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ABSTRACT

The course outline provides lesson plans, suggested visual aids, and references to source materials for a one- to five-day course originally developed by the New York City--Rand Institute for use with city agencies. The course was designed to improve the deployment of these agencies' emergency service units, and was presented to agency and city officials and to local analysts. In its present form the course can be used for fire service administrators and planning officers, police patrol administrators and planning officers, ambulance agency personnel, city officials, operations research analysts, and mixtures of these groups. It is suggested that the instructor's manual may be used for self study, since it contains all necessary references, but the student manual should only be used in a class setting, since the reference section in each lesson is left blank so that the student may keep a permanent record of his own notes. Each lesson outline is oriented specifically for a fire service, police service, or general audience, and contains a series of activities together with references and other suggestions which will enable lecturers to prepare a course, appropriate to the audience, from the lecture notes. (Author/SA)

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ED126338

A TRAINING COURSE IN DEPLOYMENT OF EMERGENCY SERVICES: STUDENT'S MANUAL

PREPARED FOR THE OFFICE OF POLICY
DEVELOPMENT AND RESEARCH, DEPARTMENT
OF HOUSING AND URBAN DEVELOPMENT

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R-1784/2-HUD
SEPTEMBER 1975

U.S. DEPARTMENT OF HEALTH,
EDUCATION & WELFARE
NATIONAL INSTITUTE OF
EDUCATION

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The New York City-Rand Institute is a nonprofit research institution founded, as its Articles of Incorporation state, "... primarily to conduct programs of scientific research and study, and provide reports and recommendations, relevant to the operations, planning or administration of the City of New York." The Institute was established in 1969 by the City of New York and The Rand Corporation as a center for the continuing application of scientific and analytic techniques to problems of urban life and local government. It is governed by a Board of Trustees appointed jointly by the City and Rand.

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PREFACE

The development, documentation, and field presentation of this course was performed under a contract with the Office of Policy Development and Research of the U.S. Department of Housing and Urban Development (HUD)--"Contract for the Development, Field Testing, and Documentation of Management Methods for Emergency Services for Local Agencies." This contract and earlier contracts between HUD and The New York City-Rand Institute involved work with city agencies designed to improve the deployment of their emergency service units. Prior to beginning such work, a training course was often presented to agency and city officials, and to local analysts.

This manual provides lecture notes, visual aids, and references for such a course, to be used by students whose instructor is teaching from the companion volume:

> R-1784/1-HUD, *A Training Course in Deployment of Emergency Services: Instructor's Manual*.

This student's manual is not designed for self-directed study. The companion instructor's manual is more suitable for this purpose.

ACKNOWLEDGMENTS

This work was supported by the Office of Policy Development and Research of the U.S. Department of Housing and Urban Development. Many of the lecture notes and visual aids are based on materials developed over a period of several years by our colleagues at The New York City-Rand Institute, and we wish to thank them all:

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INTRODUCTION

This student's manual provides lecture notes and visual aids for a course in deployment of emergency services. It is not self-contained but is designed for use in accordance with the directions of the instructor. The instructor will not present all the lectures in this volume, as there are pairs of lectures (identified by the same first initial) that cover the same topics from different perspectives. Space is provided on each page for any notes or references that the student may wish to record.

GENERAL NOTES AND ASSIGNMENTS

LECTURE OF

INTRODUCTION AND OVERVIEW FOR FIRE SERVICE AUDIENCES

Time: Approx. 40 minutes

Objective: To provide an overview of the fire service problems that will be discussed in the course, and to provide an introduction to systems analysis.

Activity	References and Notes
1. INTRODUCTION • Explain nature of course, audience, and objectives • Describe schedule for entire course 2. DEFINITION OF "DEPLOYMENT ANALYSIS" • Strategic issues -- How many companies on duty .. may vary by time of day or season -- How divided among subregions of city -- Where stations are located -- Nature of vehicles (engines, ladders, foam units, etc.); manning -- Manpower scheduling • Tactical issues -- (Not fireground tactics) -- Number and types of companies dispatched to an alarm .. may vary with time of day, location of alarm, current situation, available information -- Which units to dispatch -- Relocation (move-up) .. when needed .. how many companies move .. which ones move	

Activity	References and Notes

3. STEPS IN "SYSTEMS ANALYSIS"
(A systematic approach to solving problems)

- Identify the problem
- Select objectives
- Define criteria to be used to evaluate alternative policies
- Design alternative policies
- Select models to be used
- Collect required data
- Compare alternatives using criteria
- (Return to an earlier step)
- Test out and implement final choice

4. PROBLEMS

- This course will deal with the strategic and tactical issues of deployment analysis

5. OBJECTIVES
May be several. Some of the most common are:

- Improve fire protection levels with same resources
- Maintain fire protection levels with less resources
- Decrease workload while maintaining fire protection levels

Activity	References and Notes

6. RELEVANT CRITERIA (PERFORMANCE MEASURES)
   (Used to tell if one policy is better than another policy)

   - Time until dispatch of companies
   - Turnout time
   - Travel time
     - -- Can be average or maximum or something else
     - -- To first-arriving company,
       max (first engine, first ladder),
       max (all companies needed),
       or other measures of travel time
   - Setup time

   The above four constitute "response time." Usually must pay attention to the largest one. Deployment analysis focuses on changes that can affect travel time.

   - Coverage measures
   - Workload balance
   - Insurance grading standards?
   - Cost

   Why not lives lost, property lost?

   - Hard to measure
   - Needs research to be able to estimate changes (relationship not known precisely enough)
   - We use suitable surrogate measures

Activity

References and Notes

7. ALTERNATIVE POLICIES

- Include base case (for comparison)
- Take political and economic factors into account (including community and labor union concerns)
- Alternatives may be suggested by fire department or city personnel, or may come from mathematical models

8. MODELS

Purpose: To introduce terminology, not to illustrate any particular models

- Definition: abstraction of reality. Used to gain insight into and answer questions about the real world. Easier, safer, and less costly to use than manipulating real world.
- Empirical models
  - -- Fit to data
    - .. May have no explanation
    - .. May be mathematically complicated
  - -- Examples
    - .. Smooth fit to alarm rate by time of day
    - .. How long to travel a given distance
    - .. Chance that an alarm at a particular location is serious

Activity	References and Notes

8. MODELS (continued)

- Descriptive analytical models

  -- Using simplified assumptions, some kind of mathematical formula is derived to permit estimating some performance characteristic(s)

  -- The numbers that go into such a model may come from empirical models

  -- Examples
    - .. Knowing number of engines and ladders on duty, estimate average response distance
    - .. Knowing where fires are and how many units dispatched, estimate number of responses for each unit (workload)
    - .. If fire station is moved, what happens to response time

- Optimization models (prescriptive)

  -- Tell how to achieve the most or the least of something

  -- Examples
    - .. What is the least number of engine stations needed so that each location is within 3/4 mile of a station?
    - .. How should 17 stations be located so as to minimize average response time?
    - .. What is the smallest number of engines needed to relocate on a second alarm (if specified coverage is to be achieved)?

Activity | References and Notes

8. MODELS (continued)

- Simulation models
  - -- Imitate operations step by step
  - -- Collect all kinds of statistics
  - -- Can be extremely accurate
  - -- Doesn't tell you what to do
  - -- Things you try will be suggested by other models
  - -- Likely not to be useful until close to the end of analysis; but have to start early to collect data

9. TECHNICAL ASSISTS TO DEPLOYMENT

- Computer-assisted dispatch
- Digital communication with fire units
  - -- Status
  - -- Inspection information
  - -- Location of fire, hydrants, etc.
  - -- Screen or printer
- Packaged systems for collecting, summarizing, or projecting alarm rate information

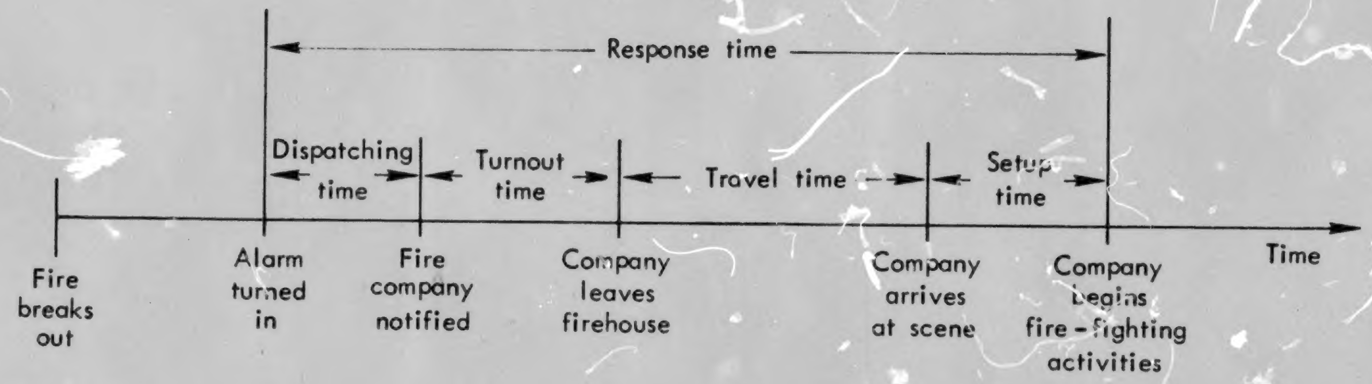
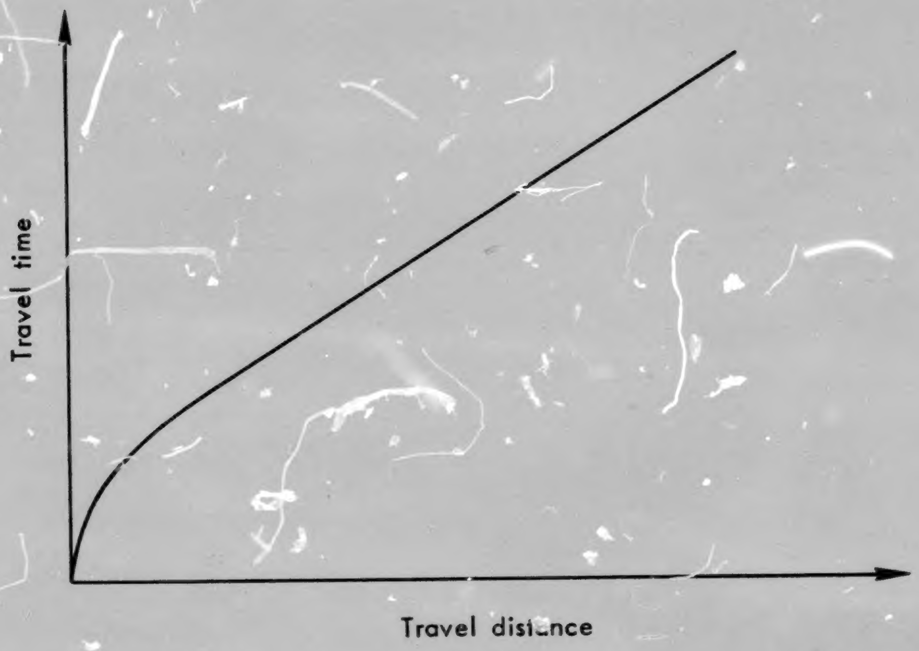

Response time
Dispatching time
Turnout time
Travel time
Setup time
Fire breaks out
Alarm turned in
Fire company notified
Company leaves firehouse
Company arrives at scene
Company begins fire-fighting activities
Time

Fig. OF-1



NOTE: The scale on each axis will vary from city to city.

Fig. OF-2

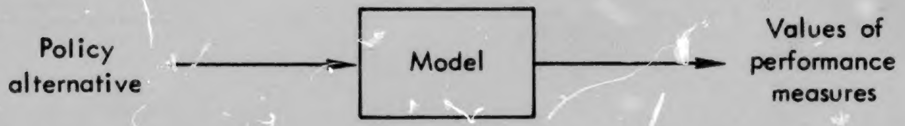

Policy alternative
Model
Values of performance measures

Fig. OF-3 — The role of a descriptive model in deployment analysis

LECTURE RF

RULES OF THUMB
FOR FIRE SERVICE AUDIENCES

Time: Approx. 50 minutes

Objective: To provide some easy to learn, easy to apply formulas and rules used in deployment analysis.

Activity	References and Notes
1. AVERAGE NUMBER OF COMPANIES BUSY	

$$= \left(\begin{array}{c}\text{AV. NUMBER}\\ \text{OF ALARMS}\\ \text{PER HOUR}\end{array}\right) \times \left(\begin{array}{c}\text{AV. NUMBER OF}\\ \text{COMPANY-HOURS}\\ \text{PER ALARM}\end{array}\right)$$

- Example

  4 alarms per hour (all types)
  30 minutes average time out-of-service
  1.2 engines per alarm, average

  4 x (0.5 x 1.2) = 2.4 engines busy on average

- AVERAGE NUMBER OF COMPANIES AVAILABLE
  = TOTAL NUMBER OF COMPANIES
  - (AVERAGE NUMBER BUSY)

2. $\left(\begin{array}{c}\text{AVERAGE TRAVEL DISTANCE}\\ \text{in a region}\end{array}\right) =$

$$(\text{CONSTANT}) \times \sqrt{\frac{\text{AREA OF REGION}}{\text{NO. COMPANIES AVAILABLE}}}$$

- Introduce notion of square root simply, via $3^2 = 9$ and therefore $\sqrt{9} = 3$

Activity

References and Notes

2. AVERAGE TRAVEL DISTANCE (continued)

- Give simple geographical demonstration showing why the rule of thumb is true

  -- Base case

  -- Double all dimensions: area quadruples, average travel distance doubles (i.e., goes up by square root of area)

  -- Repeat region 4 times: same area as in RF-2 with quadruple the companies, average travel distance is only halved (i.e., goes down as the square root of the number of companies)

  -- Halve all dimensions in RF-3: same area as RF-1 with quadruple the companies, average travel distance is halved (shows how hard it is to decrease travel times by adding companies; to halve travel times must quadruple the number of companies)

- Number of companies available changes from time to time. If the average number available in a region is not too small, the average travel distance can be estimated by replacing "NO. COMPANIES AVAILABLE" with "AV. NO. COMPANIES AVAILABLE."

- Note that this relationship assumes companies are spread out in region. Two companies in one house reduce by one the effective number of companies available (for travel distance purposes)

- This is an example of an analytical model that has been verified against data

Activity	References and Notes
3. RELATIONSHIP OF TRAVEL TIME TO TRAVEL DISTANCE • Travel time is an important criterion for evaluating deployment policies; it is clearly related to travel distance, but how • This is an example of an empirical model • Show usual shape of curve--square root blending into a straight line • Discuss underlying model of acceleration to cruise speed and then deceleration (no equations) • Emphasize that if you extend the straight line to the axis, it looks as if turnout time is included, but that's not what's happening	

Activity | References and Notes

4. ALARMS DO NOT OCCUR AT ORDERLY, PREDICTABLE TIMES, AND SERVICE TIMES DO NOT ALWAYS EQUAL THE AVERAGE
(If they did, deployment analysis would be easy)

Purpose: To introduce probabilistic notions, and suggest that mathematical models "understand" that sometimes the situation can be much worse than average

- If average number of alarms is 2 per hour at a certain time of day (such as Friday, 4-6 p m.), then

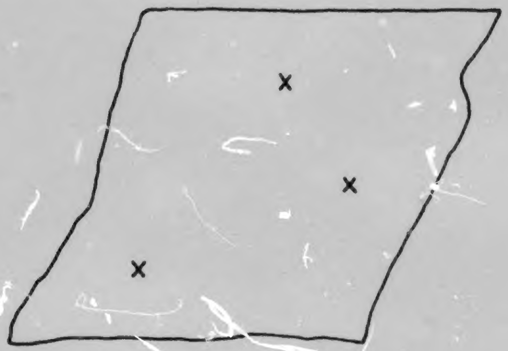
14% of such hours will have no alarms
27% of such hours will have 1 alarm
27% of such hours will have 2 alarms
18% of such hours will have 3 alarms
9% of such hours will have 4 alarms
5% of such hours will have 5 or more alarms

- Discuss what "x% of hours" means

- 2 alarms (the average) is not even more likely to occur than 1 alarm

- There are influences other than random that can make some Friday nights especially busy or quiet

  -- Weather (e.g., brush fires)
  -- Holiday (e.g., July 4)

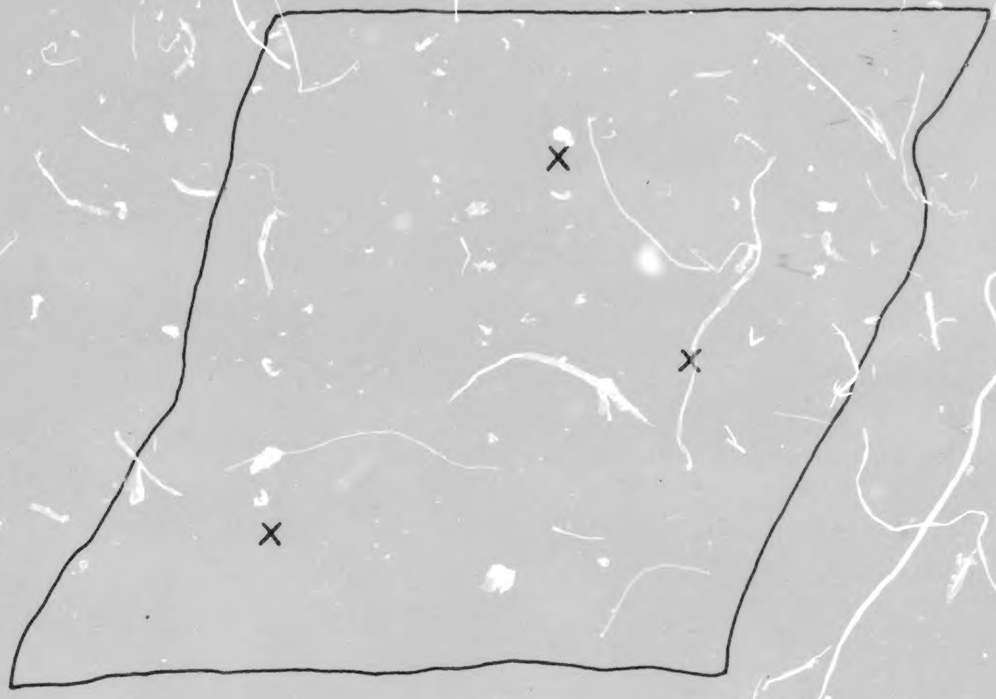


Average travel distance = D

Area = A

Number of units = N (3)

Fig. RF-1

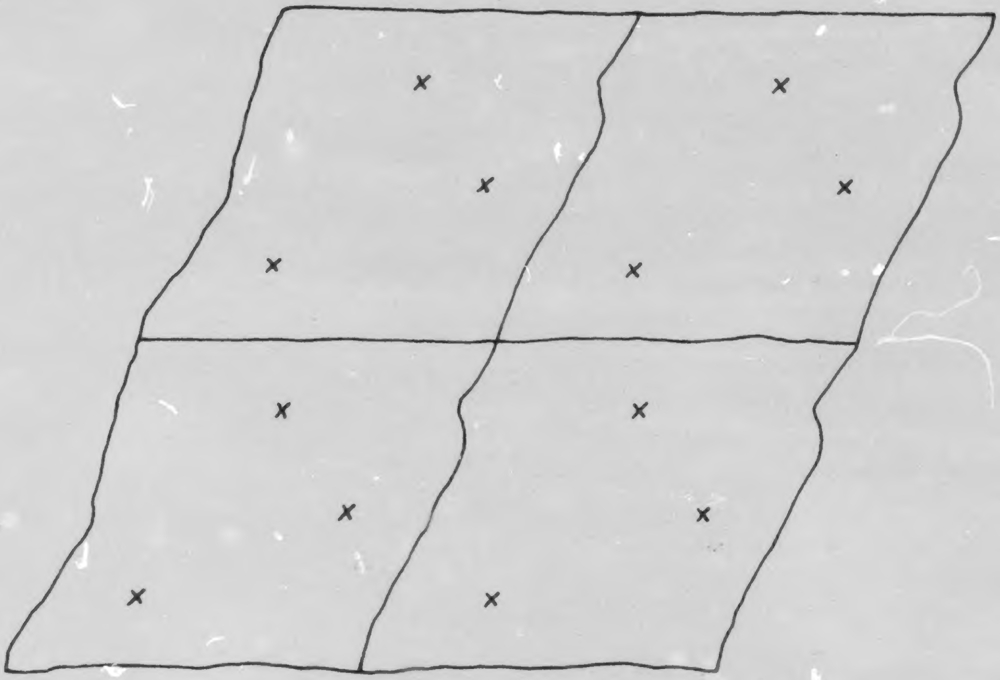


Area = 4A

Average travel distance = 2D

Number of units = N

Fig. RF-2

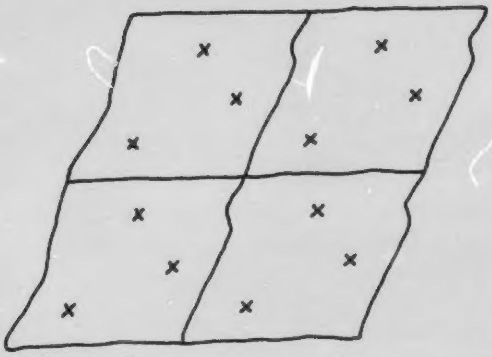


Average travel distance = D

Area = 4A

Number of units = 4N

Fig. RF-3



Average travel distance = 1/2 D

Area = A

Number of units = 4N (12)

Fig. RF-4

LECTURE OP

INTRODUCTION AND OVERVIEW FOR POLICE SERVICE AUDIENCES

Time: Approx. 40 minutes

Objective: To provide an overview of the police patrol resource allocation problems that will be discussed in the course, and to provide an introduction to systems analysis

Activity	References and Notes
1. INTRODUCTION	
• Explain nature of course, audience, objectives	
• Describe schedule for entire course	
2. DEFINITION OF "PATROL"	
• Uniformed officers in mobile vehicles who can respond to calls for service	

Activity

References and Notes

3. DEFINITION OF "ALLOCATION"

- How many men on duty
  - Varies by day and time of day
- Mode of patrol
  - One-man cars
  - Two-man cars
  - Scooters
- How many units in each geographical command
- Design of patrol beats for each unit
- Priorities attached to different types of calls (screening)
- When calls are queued (stacked, backlogged)
- Number of units dispatched
  - Varies with location and type of calls
- Which units dispatched
  - Type
  - Closest unit?
  - Beat car?
  - Across command boundaries?
- Redeployment as unavailabilities occur
- Manpower scheduling
- Scheduling of "other" unavailabilities

Activity | References and Notes

4. STEPS IN "SYSTEMS ANALYSIS"
(A systematic approach to solving problems)

- Identify the problem
- Select objectives
- Define criteria to be used to evaluate alternative policies
- Design alternative policies
- Select models to be used
- Collect required data
- Compare alternatives using criteria
- (Return to an earlier step)
- Test out and implement final choice

5. PROBLEMS

- This course will deal with the problems associated with the allocation of police patrol resources

6. OBJECTIVES
May be several. Some of the most common are:

- Improve police protection levels with same resources
- Maintain police protection levels with less resources
- Improve the balance of workload among patrol units

Activity

References and Notes

7. CRITERIA (PERFORMANCE MEASURES)

- Length of time caller must wait until unit is dispatched
- Travel time to scene
- Dispatches out of assigned area
- Balance of workload among units
- Time available for other activities
    - -- Preventive patrol
    - -- Meals
    - -- Patrol-initiated investigation
    - -- Traffic
    - -- Maintenance of vehicle
    - -- Interaction with citizens
- Cost
- Why not crime deterrence, apprehension of criminal offenders, recovery of stolen property, community sense of security?
    - -- Hard to measure
    - -- Relationship to allocation not known precisely enough
    - -- We use proxy measures
    - -- Administrators can tell what changes in performance measures (up or down) are desirable, even if they don't know the exact benefit

8. ALTERNATIVE POLICIES

- Include existing policy (for comparison)
- Take political and economic factors into account (including community and labor union concerns)
- Alternatives may be suggested by police department or city personnel, or may come from mathematical models

Activity | References and Notes

9. MODELS

Purpose: To introduce terminology, not to illustrate any particular models

- Definition: abstraction of reality. Used to gain insight into, and answer questions about, the real world. Easier, safer, and less costly to use than manipulating real world

- Empirical models
  - -- Fit to data
    - .. May have no explanation
    - .. May be mathematically complicated
  - -- Examples
    - .. Smooth fit to call rate by time of day
    - .. How long to travel a given distance
    - .. Relationship between fraction of time cars are unavailable and number of calls for service

- Descriptive analytical models
  - -- Using simplified assumptions, some kind of mathematical formula is derived to permit estimating some performance characteristic(s)
  - -- The numbers that go into such a model may come from empirical models
  - -- Examples
    - .. Knowing number of units on duty, estimate average travel time to an incident
    - .. Knowing number of units on duty, estimate fraction of serious emergencies encountering a delay before dispatch
    - .. Knowing the patrol area of each unit and location of incidents, estimate workload and fraction of out-of-district dispatches for each unit

Activity	References and Notes

9. MODELS (continued)

- Optimization models (prescriptive)
  - -- Tell how to achieve the most or the least of something
  - -- Examples
    - .. How should sectors be designed to minimize average travel time to incidents?
    - .. How should a fixed total number of man-hours be distributed among tours so as to minimize the chances that a caller will have to wait before dispatch of a patrol car?

- Simulation models
  - -- Imitate patrol operations step by step
  - -- Collect all kinds of statistics
  - -- Can be extremely accurate
  - -- Don't tell you what to do
  - -- Things you try will be suggested by other models
  - -- Likely not to be useful until close to the end of analysis; but have to start early to collect data

LECTURE RP

RULES OF THUMB FOR POLICE SERVICE AUDIENCES

Time: Approx. 80 minutes

Objective: To provide some easy to learn, easy to apply formulas and rules used in police patrol resource allocation analysis

Activity	References and Notes

1. AVERAGE NUMBER OF UNITS BUSY HANDLING CALLS FOR SERVICE

$$= \begin{pmatrix} \text{AVERAGE NUMBER} \\ \text{OF CALLS} \\ \text{PER HOUR} \end{pmatrix} \times \begin{pmatrix} \text{AVERAGE} \\ \text{UNIT-HOURS} \\ \text{PER CALL} \end{pmatrix}$$

- Give an example

  2 calls per hour, average
  1 car handles each
  Average length of time to handle call, 30 minutes

  On the average, 1 car is busy
  If 2 cars on duty, each is busy $\frac{1}{2}$ the time
  If 4 cars on duty, each is busy $\frac{1}{4}$ the time

- Number of units on duty must at least equal average number busy

Activity | References and Notes

2. EMERGENCIES DO NOT OCCUR AT ORDERLY, PREDICTABLE TIMES, AND SERVICE TIMES ARE NOT THE SAME FOR ALL CALLS
(If they did, the analysis would be easy)

- Example:
  - -- Calls occur on the hour and half-hour. Every call takes exactly 30 minutes

    1 car can handle--nobody waits
    --but car is always busy

    If 2 cars--nobody waits
    --each car is free half the time
    --always one car on patrol

  - -- But, when average number of calls is 2 per hour

    14% of hours have no calls

    27% of hours have 1 call

    27% of hours have 2 calls

    18% of hours have 3 calls

    9% of hours have 4 calls

    4% of hours have 5 calls

    1% of hours have 6 or more calls

  - -- Considering the usual spread of service times around 30 minutes

    With 1 car on duty, every caller waits

    With 2 cars on duty,
    1/3 of callers wait
    1/3 of time no car is on patrol
    Average wait until a car can be dispatched is 10 minutes (incl. no-wait)
    17% of callers wait more than 20 minutes

- Conclusion: Number of units on duty must be considerably more than average number busy

Activity | References and Notes

3. A MINIMAL STANDARD FOR ADEQUATE PERFORMANCE IS: NO MORE THAN 15% OF IMPORTANT CALLS ARE QUEUED

- Many departments don't achieve this (especially during peak hours)
- A goal set by some departments is: No more than 5% of important calls are queued
- A few departments routinely have less than 1% of important calls queued
- Impossible to guarantee that no calls will be queued

4. CARS ARE UNAVAILABLE FOR DISPATCH FOR REASONS OTHER THAN RESPONSE TO PREVIOUS CALLS

- What are these activities?
  - Meals, personal
  - Patrol-initiated crime or vehicle check
  - Notifications, warrants
  - Process arrestee
  - Supervision - field
  - Supervision - station
  - Waiting
  - Travel to assigned beat
  - Transport (something)
  - Assigned to fixed location
  - Maintenance, auto
- Ordinarily, at least 30 percent of each unit's time spent on such unavailabilities
- In San Fernando Valley area of Los Angeles, average unavailabilities vary among divisions from 44% to 62% of total time on duty. In one New York precinct, 58 percent
- For queuing purposes, effective number of units on duty may be less than half the number assigned

Activity | References and Notes

5. NUMBER OF UNITS NEEDED TO MEET DESIRED LEVEL OF QUEUING DOES NOT INCREASE PROPORTIONATELY WITH NUMBER OF CALLS

- Example:

  A command with 2 calls per hour needs 7 units. This is not twice the number needed in a command with 1 call per hour (namely, 5 units)

6. AVERAGE NUMBER OF MINUTES BETWEEN PASSINGS OF A RANDOM POINT BY UNIT ON PATROL $\approx$

$$6 \times \frac{\text{NUMBER OF STREET MILES IN BEAT}}{\text{FRACTION OF TIME AVAILABLE}}$$

- Nobody has proved from data that preventive patrol deters crime
- Mention Kansas City Proactive-Reactive Patrol Experiment

Activity | References and Notes

7. AVERAGE TRAVEL TIME $\approx$ 2 min $\sqrt{\dfrac{\text{AREA (in sq miles)}}{\text{NO. UNITS AVAIL.}}}$

- Example:

  Area of command is 6 square miles
  5 patrol cars on duty
  Each available 60% of time

  Average travel time $\approx$ 2 min $\sqrt{6/3}$ = 2.83 min

- Why this is a general principle

- Total response time =

  (dispatching delay)
  + (queuing delay)
  + (travel time)

- Reducing response time increases probability of apprehending offender at the scene, but the effect is important only if very short response times can be achieved

- Reducing travel time can help to reduce response time into the useful range if queuing delays are short. It makes no sense to reduce travel times when queuing delays are long

Activity | References and Notes

8. WHAT CAN YOU DO WITH PRIORITIES?

- If queue forms, dispatch free unit to oldest highest priority call
    - Average delay the same
    - Delay for high-priority calls is less
- Hold one or two units in reserve for high-priority calls
    - Regular beat car
    - Special unit
    - Average delay is more
- Screen out low-priority calls when busy
    - "Adaptive dispatch policy"
- Schedule low-priority calls for handling at a more convenient time

9. WHAT'S WRONG WITH $\left\{\begin{matrix}\text{WORKLOAD}\\ \text{HAZARD}\end{matrix}\right\}$ FORMULA?

- Description of Hazard Formula
    - $F_j = j^{th}$ factor
    - Examples:

      Number of outside violent crimes
      Number of other Part I crimes
      Number of street miles
      Number of arrests
      Number of commercial establishments
      Number of emergency calls
    - f_{ij} = amount of factor j in command i
    - $F_j = f_{1j} + f_{2j} + f_{3j} + \dots + f_{Nj}$
    - w_j = "importance" of factor j
    - $H_i = w_1 \frac{f_{i1}}{F_1} + w_2 \frac{f_{i2}}{F_2} + \dots + w_M \frac{f_{iM}}{F_M}$
    - Manpower proportional to H_i

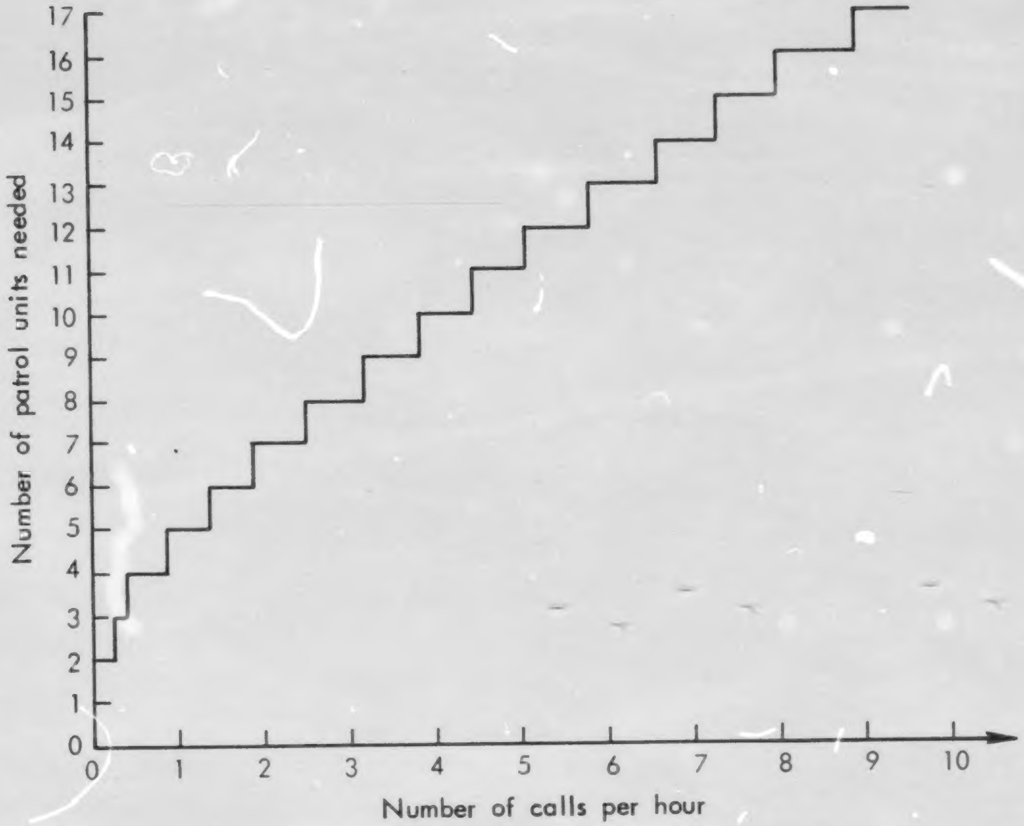
Activity | References and Notes

9. WHAT'S WRONG WITH $\left\{\begin{matrix}\text{WORKLOAD}\\ \text{HAZARD}\end{matrix}\right\}$ FORMULA? (continued)

- Description of Workload Formula
    - -- w_j = number of man-hours associated with factor j
    - -- $H_i = w_1 f_{i1} + w_2 f_{i2} + \ldots + w_M f_{iM}$
    - -- Manpower proportional to H_i
    - -- Mathematically the same as Hazard Formula with different weights
- Problems
    - -- Apples and oranges
    - -- Interrelated
    - -- Proportional increase for emergency calls
    - -- No way to determine "correct" weights for Hazard Formula
    - -- Workload Formula accomplishes only one objective: equalizing workload
    - -- Hazard Formula does not do what it appears to do

      Example: Assume precincts with high numbers of outside crimes have proportionately more unimportant calls. Then increasing w_j for outside crimes decreases manpower assigned to high-crime precincts
    - -- No credit for good performance
- May be useful for manpower needs other than patrol

Number of patrol units needed so
that at most 10% of calls delayed



Assumptions: 30 minute service time per call
50% of each car's time spent
unavailable for reasons other than dispatch to a call

Fig. RP-1

LECTURE CG

CHARACTERISTICS OF EMERGENCY SERVICES FOR GENERAL AUDIENCES

This lecture is intended for audiences of analysts interested in the similarities and differences among emergency services and for audiences containing a mixture of fire, police, and ambulance service representatives.

Time: Approx. 60 minutes

Objective: To describe the general characteristics of emergency services that are relevant for deployment analyses

Activity

References and Notes

1. INTRODUCTION

- Some models developed for one emergency service can be applied directly to another service, changing only terminology. Others are unique to a particular service because of distinct characteristics
- Considering only police patrol, fire units, and emergency medical services

2. CALLS FOR SERVICE

- Arrival process

  All three services: Poisson by time and geography. Rate varies by hour about an order of magnitude. Any method that predicts demands for one service will also work for others

- Priority structure

  Police and ambulance: priorities can be identified; some calls are not time-urgent; some calls can be rejected when necessary to prevent system congestion, but there may be legal constraints on call rejection

  Fire: information for distinguishing type of call may be absent (e.g., street box alarm); when present, information does not determine priority, but only the number and type(s) of units needed

Activity

References and Notes

3. TYPES OF UNITS

Police: usually all patrol units are interchangeable from the point of view of the functions they can perform when they reach the scene

Fire: at least two types: engines and ladders; limited interchangeability

Ambulances: may have distinguishable capabilities: transport only, routine treatment, or intensive care (medic units, mobile cardiac care units)

4. MANNING

Police: 1 or 2 officers. If both types are present in same city, two 1-man units may be needed as an alternative to one 2-man unit

Fire: 3 to 7 fire-fighters

Ambulance: standard is now 2 attendants; some agencies do not achieve this

5. LOCATION OF UNITS

Police: mobile. Patrol areas can in principle be designed in any way desired, but administrative constraints are often imposed. Patrol areas can also change during or between tours of duty, but this is becoming less common with the advent of "neighborhood teams." Overlap of sectors possible, but not done in most cities. Geometrical probability models for two or more randomly located points relevant

Fire and ambulance: usually fixed locations. "Patrol" activities such as inspection infrequent; can ignore in most cities. May be several units at one location. Type of physical structure not important for ambulances (garage, hospital, police station, fire station). Fixed location implies "turnout" time

Activity	References and Notes
6. HOW MANY UNITS ON DUTY Police and ambulance: flexible by day and time Fire: usually not varied over the day; a long-term planning issue	
7. QUEUING OF CALLS DUE TO UNAVAILABILITY OF UNITS Police: common in many cities. Wait may dominate travel time. Queue usually has priority structure in practice Ambulance: common in a few cities. Happens occasionally in many cities Fire: Only under crisis conditions. Not relevant for deployment analysis	
8. HOW MANY UNITS DISPATCHED Police: usually one. For some calls two 1-man cars are dispatched. In practice, more units may respond than are dispatched Fire: usually at least two. In some cities as many as 5-7. Traditionally preplanned according to: (a) nature of land use (business, residential, high rise) (b) nature of incident Analysis can consider time of day, projected incidence rates, current unavailability status of system, probability that incident is serious, manning on unit Ambulance: usually one. Some systems dispatch two or three, having different capabilities (a) First responder has limited capabilities; second has full treatment and transport capabilities (b) First has full treatment capabilities but cannot transport; second can transport	

Activity	References and Notes
9. WHICH UNIT(S) DISPATCHED	
Police: usually sector car if available. If not available, several policies are possible	
Fire: traditionally preplanned. Almost always closest available, on initial dispatch	
Analysis shows this may not be optimal	
10. RELOCATION	
Fire: traditionally preplanned for multiple-alarm fires. May be needed for several simultaneous smaller fires. Explain purpose	
Police and ambulance: rarely used, but would have same benefits as in fire case	
11. UNAVAILABILITY FOR REASONS OTHER THAN PREVIOUS DISPATCH	
Fire and ambulance: recovery from previous incident only	
Police: substantial part of activity. May amount to 35%-60% of time. Some of these unavailabilities could be interrupted by high-priority incident	

Activity | References and Notes

12. PERFORMANCE CRITERIA

(a) Queuing concepts

Fire: delays by dispatchers; probability that all or most units assigned to a subarea will be busy

Police and ambulance: dispatch delays, expected time in queue, probability of waiting > T in queue, delays by priority level

(b) Travel time

Fire: is a vector (by order of arrival and type of unit)

Police and ambulance: relevant for certain calls

(c) Turnout time

Fire and ambulance

(d) Workload balance

All three

(e) Dispatches out of usual area

Police

(f) Time available for nondispatch functions

Police

(g) Cost of operation

All three

LECTURE DF

DATA ANALYSIS FOR FIRE SERVICE AUDIENCES

Time: Approx. 60 minutes

Objective: To introduce students to types of alarm patterns and their usefulness, and to suggest approaches for analyzing data.

Activity	References and Notes
1. DEFINITION OF DATA ANALYSIS	
• Emphasize the view of discovering patterns that allow deployment to be improved	
• Indicate that variation is expected, otherwise play it down	
• Give example of a nonuseful pattern (Thursday is Tacoma, Washington's slowest day)	
• Say that usual computer reports are not sufficient for data analysis, although possibly useful for management purposes	
2. COMMON PATTERNS--THEIR RELIABILITY AND USE	
• Let the audience help identify and classify them	
• Do geography, type of incident, trend, season, day of week, time of day (optional--weather)	
• Structural fires may have different patterns than false alarms; patterns of total alarms, structures, and false alarms will all be illustrated	

Activity | References and Notes

3. HAZARD REGIONS
(Also called demand regions)

- Indicate need for dividing city into regions
- Characterize a good definition
    - -- Start with a description of an ideal (fictional) region: uniformity of land use, alarm patterns, structures, etc.
    - -- Less variation within regions than between regions
    - -- End with the notion that the division into regions is successful if no one feels they should ask, "But are response times in the north part of the region higher or lower than in the south?"
    - -- May be convenient to have each hazard region be a set of company administrative areas or census tracts
- Display alarms per capita and alarms per square mile and indicate their use
    - -- Trend prediction (if population trend can be predicted)
    - -- Allocation model

4. TIME-OF-DAY PATTERN

To illustrate a common pattern and statistical variability around it

- Display hourly total alarms over a period of several days. Indicate
    - -- consistency (evening always higher than late night)
    - -- variation around it
- Optional: July 4 vs. average vs. slow day
- Offer weather as a partial explanation of the variation
- Ask audience for possible uses--different number of men on duty at different hours, etc. Emphasize possible--they may not be desirable uses.

Activity	References and Notes

5. TREND AND SEASON

To illustrate superposition of patterns and how to untangle effects

- Display a short pattern, indicate inadequacy (total alarms, 34 months, Tacoma)
- Display a long pattern (false alarms, 60 months, New York City)
- Display detrended seasonal pattern
  - -- Indicate that slide shows ratio of alarms in a week to the trend
  - -- Could calculate the difference between alarms in a week and the trend as alternative
  - -- Stress the economy of the ratio description
- Ask audience for possible uses

6. PATTERN "SIZE"

To indicate the possible usefulness of a pattern

- Divide previous patterns into 4 seasons and 4 six-hour periods (divide the year and the day into the same number of parts, in this case, 4)
- Calculate ratio of peak period to low period for each of the two patterns
- Compare the ratios. A big ratio indicates a pattern possibly worth trying to take advantage of
- Check statistical significance of large ratios
  - -- if ratio is large, but the data do not establish significance, gather more data
  - -- [if a small ratio is statistically significant, there may nonetheless be no policy value to the pattern]

Activity

References and Notes

7. GEOGRAPHICAL PATTERNS--LARGE AREAS

- Illustrate approximate constancy of false alarms as a fraction of box alarms throughout New York City

- Stress the economy of this constancy, as it relates to false alarms per capita or per square mile, which vary even more than total alarms illustrated in Figures DF-3, DF-4

8. GEOGRAPHICAL PATTERNS--SMALL AREAS

Purposes: To indicate that part of the data should be reserved, and used for judging the reliability of any patterns discovered and to show a pattern that was discovered because deployment models suggested that if it existed, it would be useful

- Illustrate box-to-box variability in proportion of all alarms that are false

  -- Not inconsistent with large area pattern, since no area is exclusively high or low in regard to percent false

  -- Indicate the pattern is useful only if it is consistent from year to year

Activity	References and Notes

8. GEOGRAPHICAL PATTERNS--SMALL AREAS (continued)

- Illustrate the finding and checking of the pattern of box-to-box variations in proportion of box alarms that are serious
    - These are year-round numbers
    - Box 2277 is among the lowest in predicted percent structural, box 2209 is among the highest. But they are not outliers
    - Indicate how risk classes were defined
    - Stress the role of reserving some of the data
    - Deployment models shifted attention to serious fires rather than total alarms
    - Seriousness needs careful definition, specific to the city. Depends on the purpose: Maybe all structural, maybe only those that work several companies, etc.
    - The pattern is useful when the alarm rate is high
- Indicate that season and time of day affect the pattern
    - Relatively more false alarms in summer (and evening), structural fires almost constant
    - Serious fires are a larger proportion of structural late at night, in winter (fewer food-on-stove-type incidents)
    - Illustrate the size of the overall effect: risky boxes, late night, winter vs. nonrisky, summer evening
    - Optional: Illustrate economy and good fit of separate, multiplicative seasonal and time-of-day factors

Activity | References and Notes

9. Optional: THE POISSON PROCESS

Purpose: To introduce probabilistic notions, and suggest that mathematical models "understand" that sometimes the situation is much worse than average

Suggest its nature and reasonableness. Take a finite set of "similar" hours and a fixed total number of alarms, and discuss distributing the alarms at random. ("Throwing darts at the line")

- Example--Jersey City. Very small seasonal effect (similar to Tacoma). In 1973, 1480 alarms in 2-4 p.m. period, which is 365 x 2 = 730 hours. In that period, 1480/730 = 2 alarms per hour
- Consequence--if average number of alarms is 2 per hour between 2 and 4 p.m. in Jersey City, then

  14% of such hours will have no alarms
  27% of such hours will have 1 alarm
  27% of such hours will have 2 alarms
  18% of such hours will have 3 alarms
  9% of such hours will have 4 alarms
  5% of such hours will have 5 or more alarms

- Discuss what "x% of hours" means
- 2 alarms (the average) is not even more likely to occur than 1 alarm

10. Optional: FIRE COMPANY WORK TIMES

- Discuss company work times by alarm type
- Indicate that averages may be sufficient

Activity	References and Notes
11. RECAP	
Go through the data analysis process	
• Divide the data	
-- Find patterns on one part	
-- Verify them on the other	
• Plot and cross-tabulate	
• Construct hazard regions	
• Patterns should be	
-- useful	
-- simple	

DATA ANALYSIS

What is it? Discovering and characterizing the variations and consistencies in incidents:

- Finding patterns--in time, season, location
- Variations from the patterns are often usefully treated as random, and describable by the Poisson process

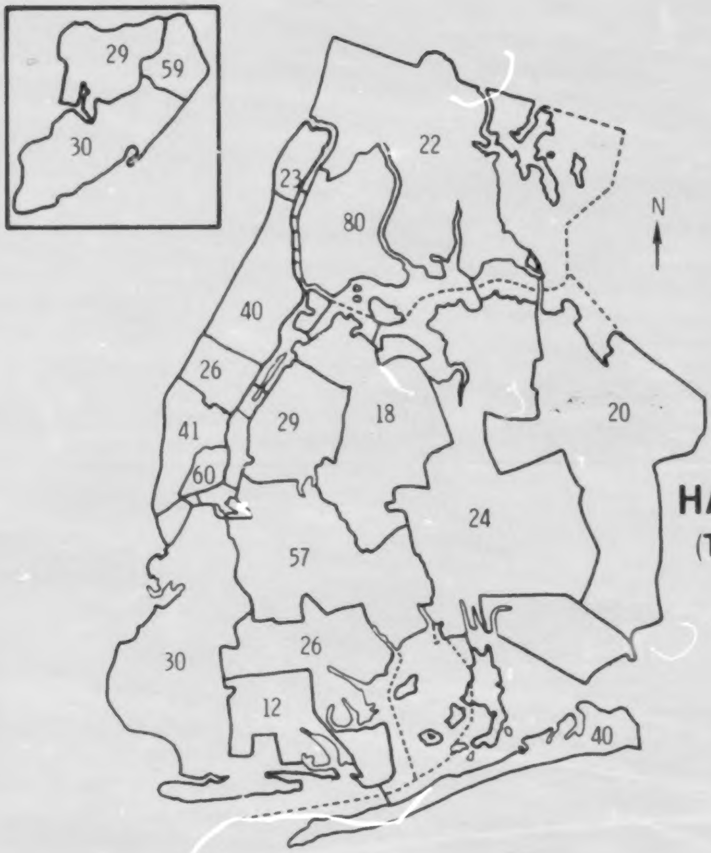
Why do it? To improve the deployment of fire-fighting resources

Fig. DF-1

COMMON ALARM PATTERNS

Pattern	Reliable	Useful For	How Much
Geographical	Relatively	Allocation	Very
Breakdown by Type	Yes	Allocation, Initial Dispatch	Some
Trend	Maybe	Allocation	Some
Season	Yes	Allocation	Slight
Day of Week	Yes	?	--
Time of Day	Yes	Initial Dispatch, Allocation	Very if alarm rate is high, slight otherwise
Weather	—	Short term allocation, for brush fires, etc.	Some

Fig. DF-2

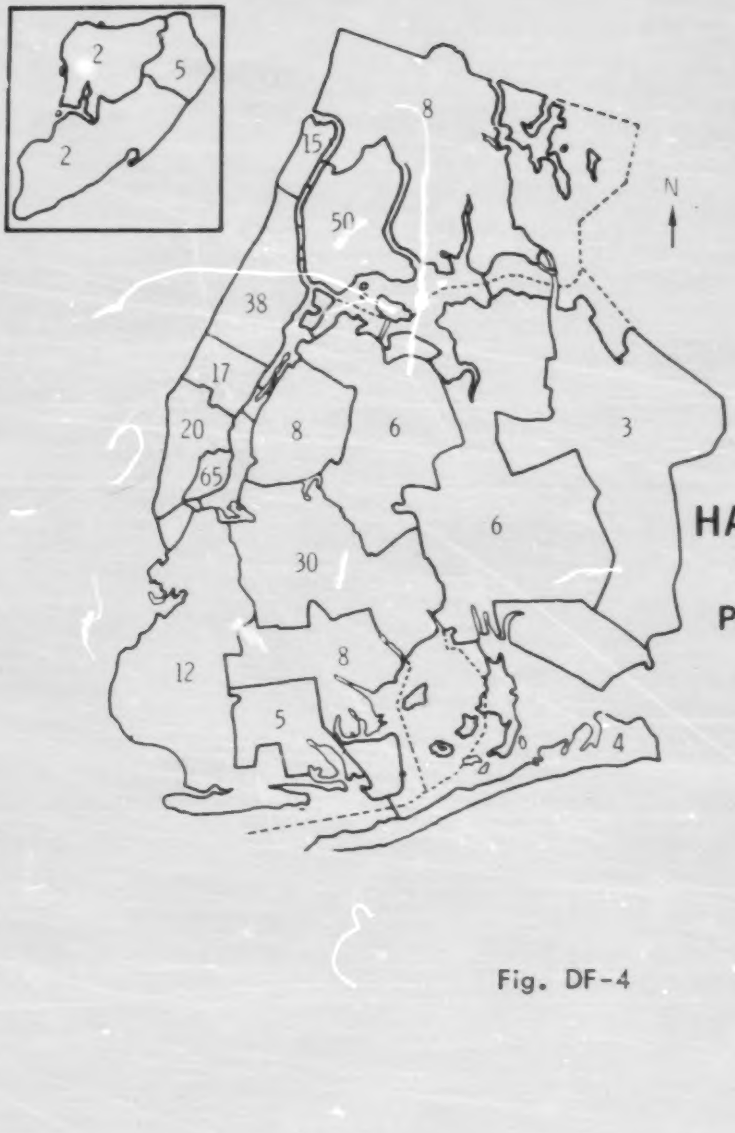

29
59
30
22
23
80
40
26
41
60
29
18
20
24
57
26
30
12
40
N

HAZARD REGION DATA

(TOTAL ALARMS PER 1000 RESIDENTS IN 1971)

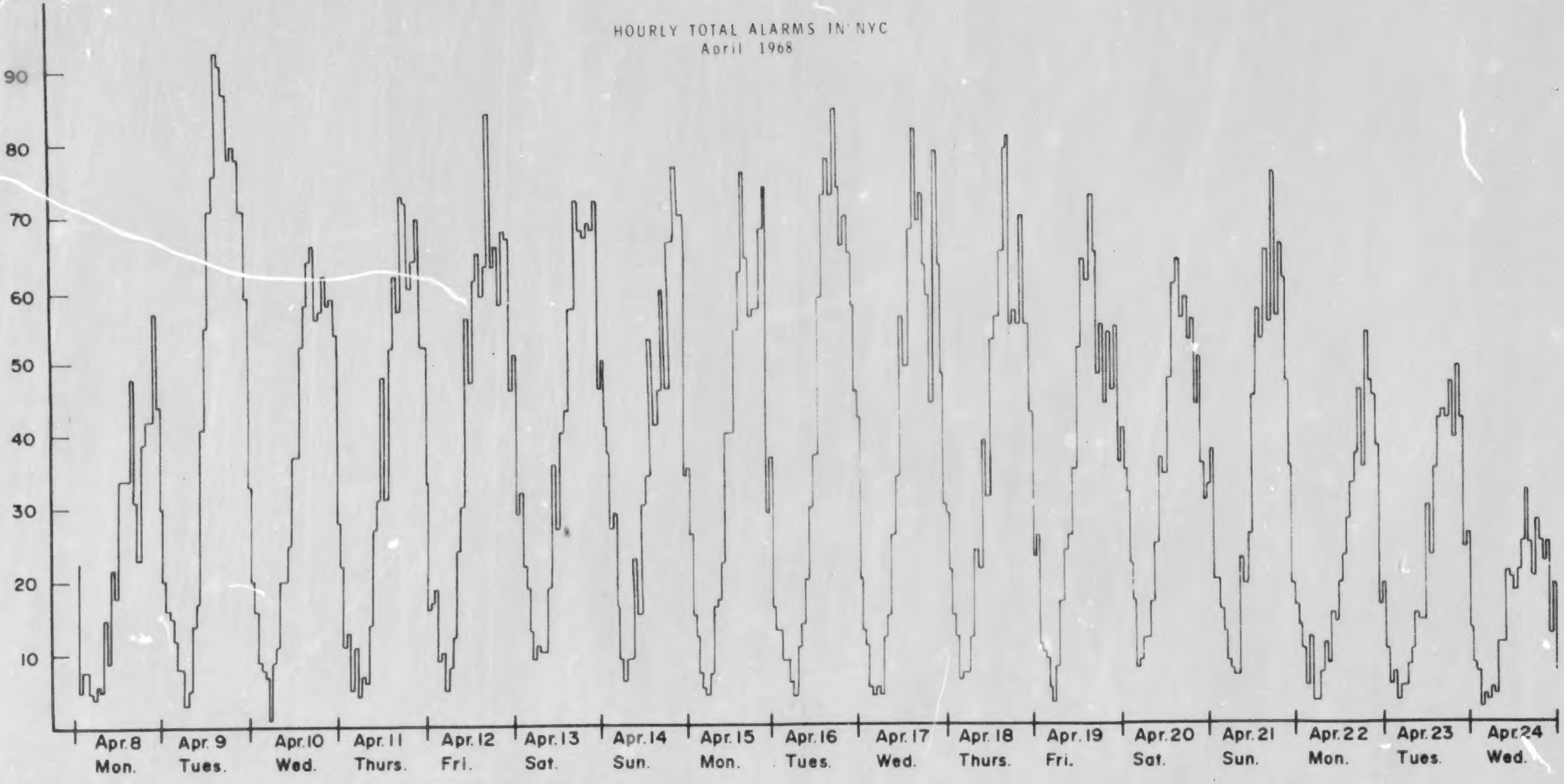
NEW YORK CITY

Fig. DF-3


2
5
2
8
15
50
38
17
20
65
8
6
3
6
30
12
8
5
4
N

HAZARD REGION DATA
(HUNDREDS OF ALARMS PER SQUARE MILE IN 1972)
NEW YORK CITY

Fig. DF-4



HOURLY TOTAL ALARMS IN NYC
April 1968

Fig. DF-5

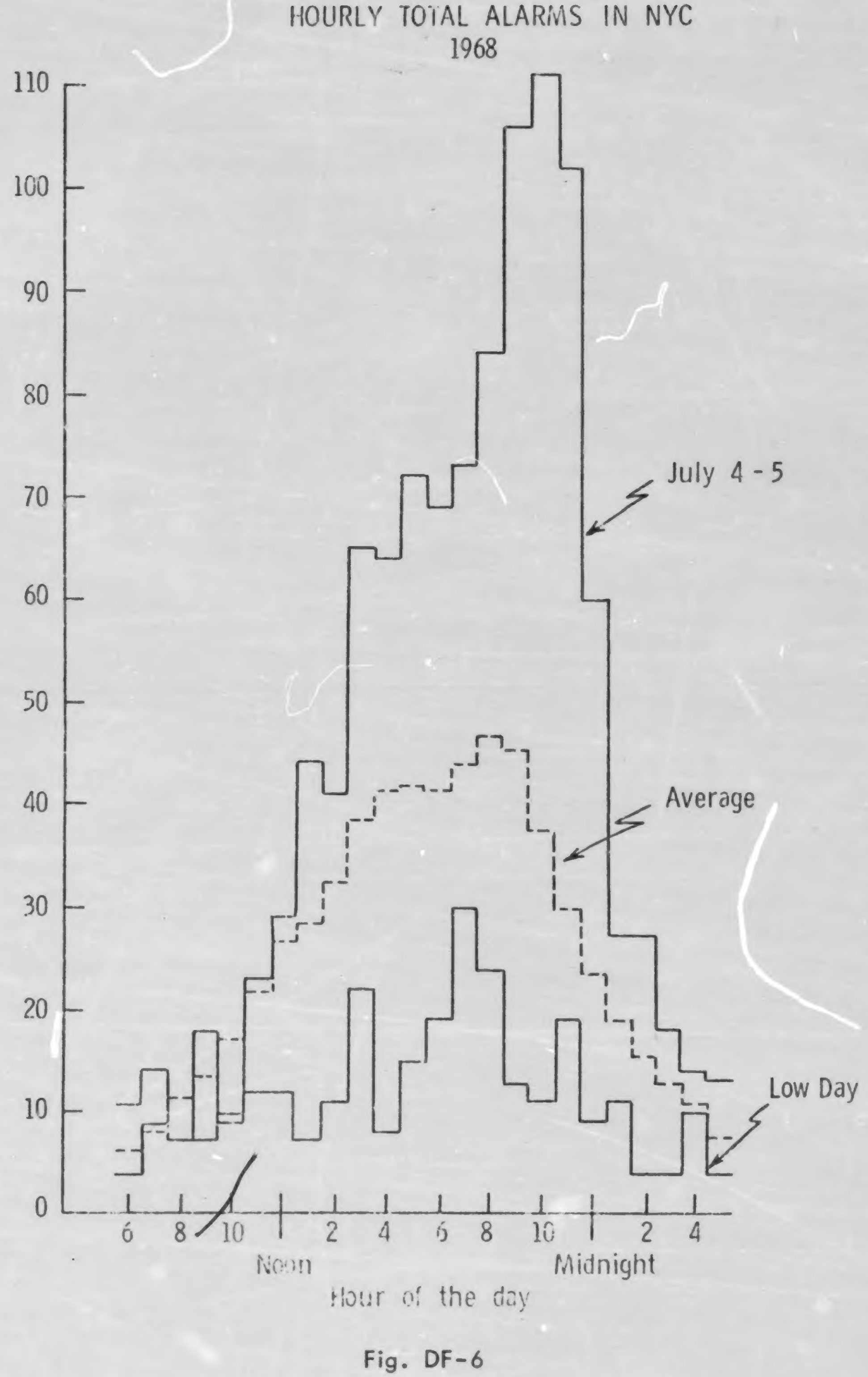
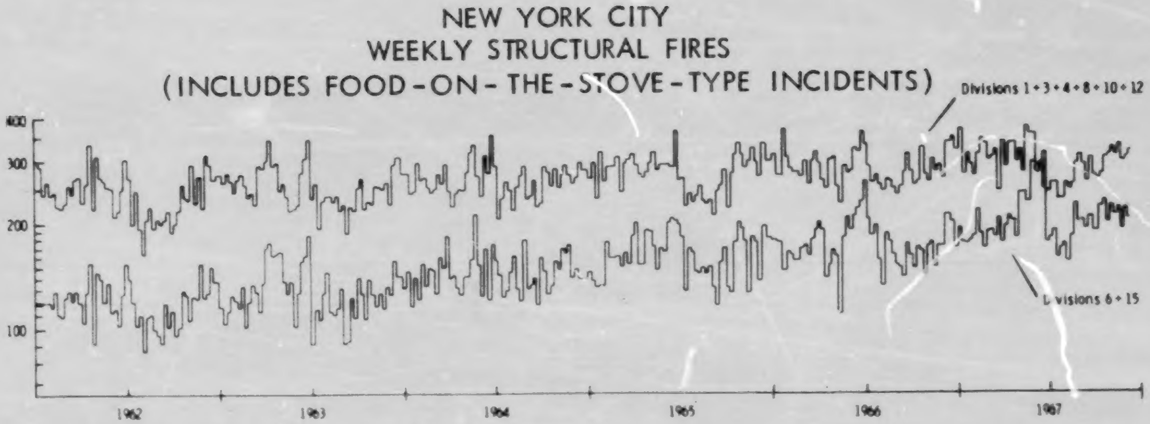

HOURLY TOTAL ALARMS IN NYC
1968
110
100
90
80
70
60
50
40
30
20
10
0
July 4 - 5
Average
Low Day
6
8
10
Noon
2
4
6
8
10
Midnight
2
4
Hour of the day

Fig. DF-6



NEW YORK CITY
WEEKLY STRUCTURAL FIRES
(INCLUDES FOOD-ON-THE-STOVE-TYPE INCIDENTS)

Fig. DF-7

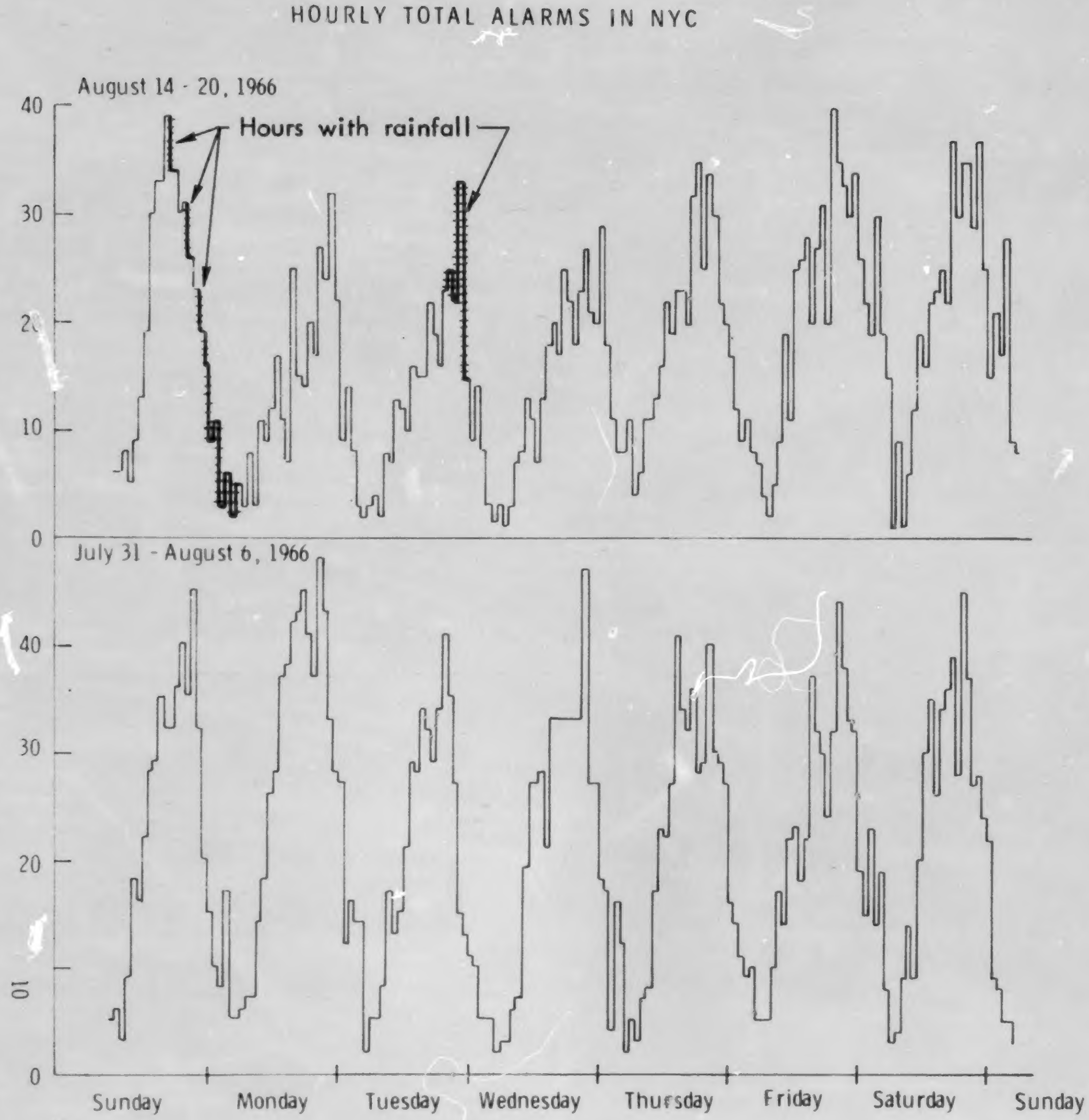

HOURLY TOTAL ALARMS IN NYC
August 14 - 20, 1966
Hours with rainfall
July 31 - August 6, 1966
40
30
20
10
0
Sunday
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday

Fig. DF-8

TACOMA, WASHINGTON

TOTAL ALARMS BY MONTH

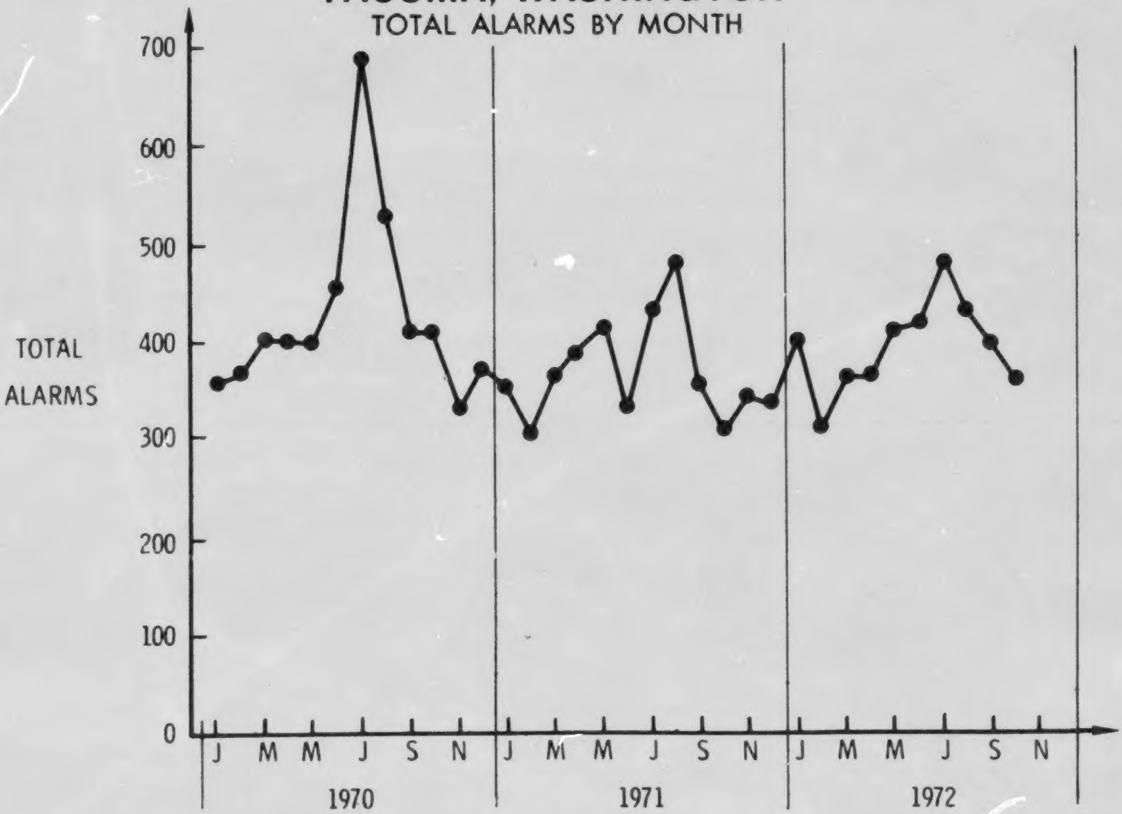


Fig. DF-9

NEW YORK CITY FALSE ALARMS BY WEEK

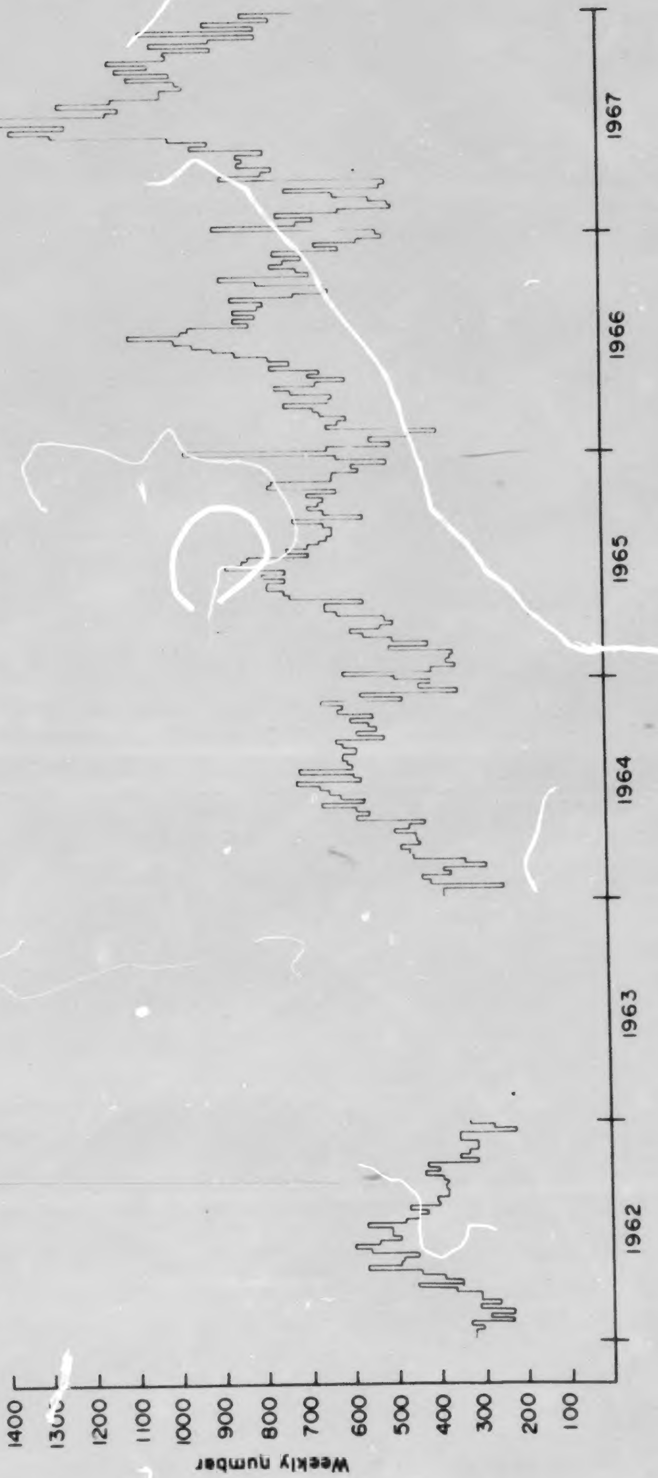


Fig. DF-10

NEW YORK CITY
RATIO OF WEEKLY FALSE ALARMS TO TREND

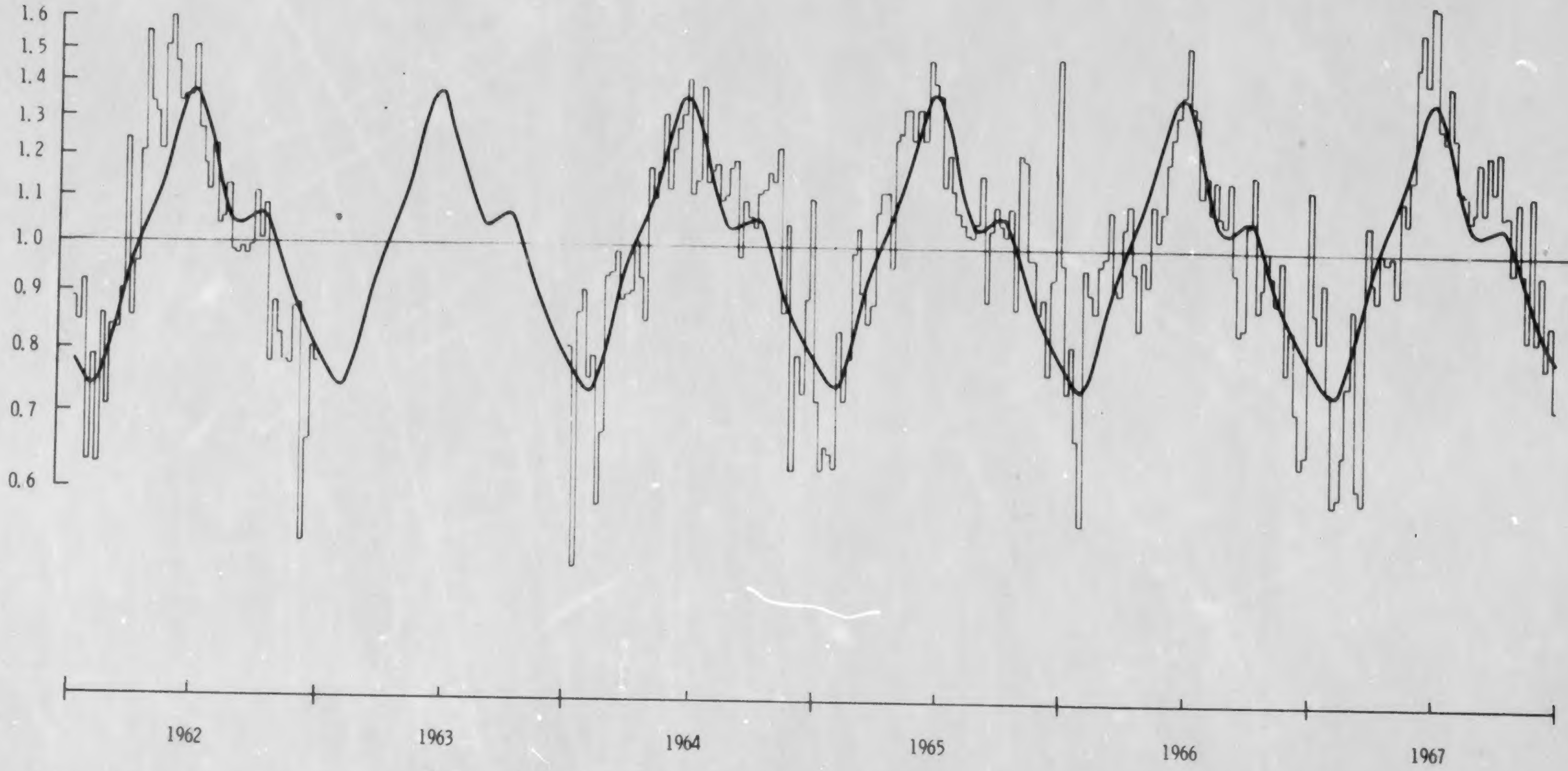


Fig. DF-11

TACOMA, WASHINGTON
(TIME OF DAY PATTERN)

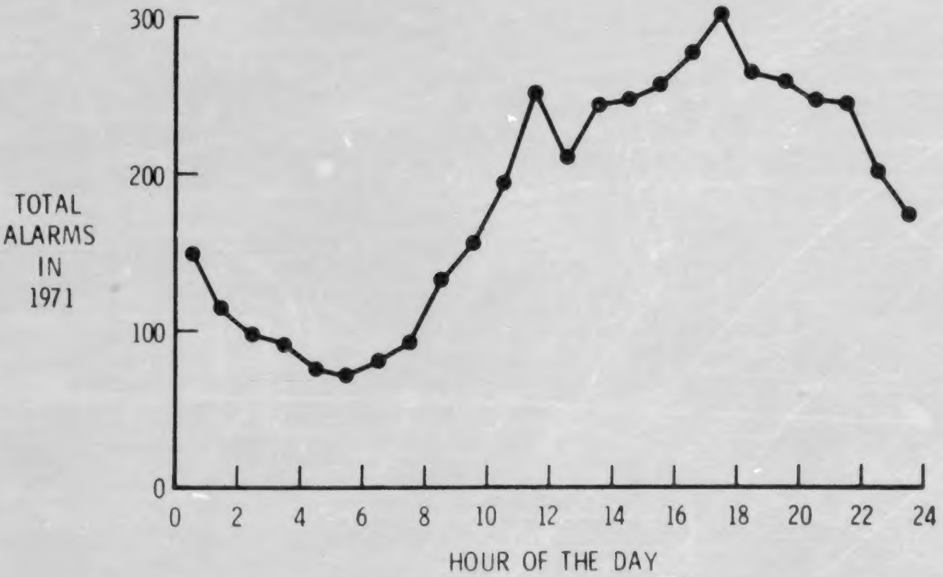


Fig. DF-12

MEASURING THE SIZE OF A PATTERN

Seasonal Pattern: Tacoma

Period		Alarms in 1971
Winter:	January, February, December	1002
Spring:	March-May	1181
Summer:	June-August	1248
Fall:	September-November	1009

High to low ratio is

1.25 = 1248/1002

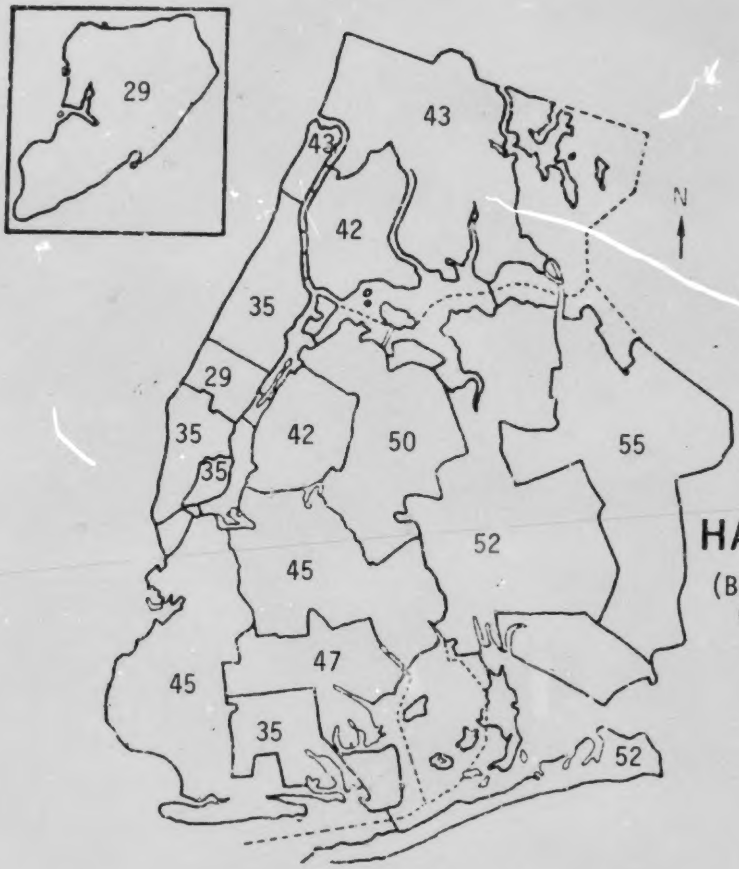
Time of Day Pattern: Tacoma

Time	Alarms in 1971
0200 - 0800	497
0800 - 1400	1195
1400 - 2000	1409
2000 - 0200	1139

High to low ratio is

2.8 = 1409/497

Fig. DF-13


29
43
43
N
42
35
29
42
50
55
35
35
52
45
45
47
35
52

NEW YORK CITY

HAZARD REGION DATA

(BOX FALSE ALARMS AS A PERCENT
OF ALL BOX ALARMS IN 1968)

Fig. DF-14

STRUCTURAL FIRE PREDICTIONS FOR TWO ALARM BOXES

Bronx box number	Predicted percent structural ('67 - '69 data)	Actual 1970 Data	
		Alarms	Structural fires
2277	0.4	96	0
2209	31.8	94	25

Fig. DF-15

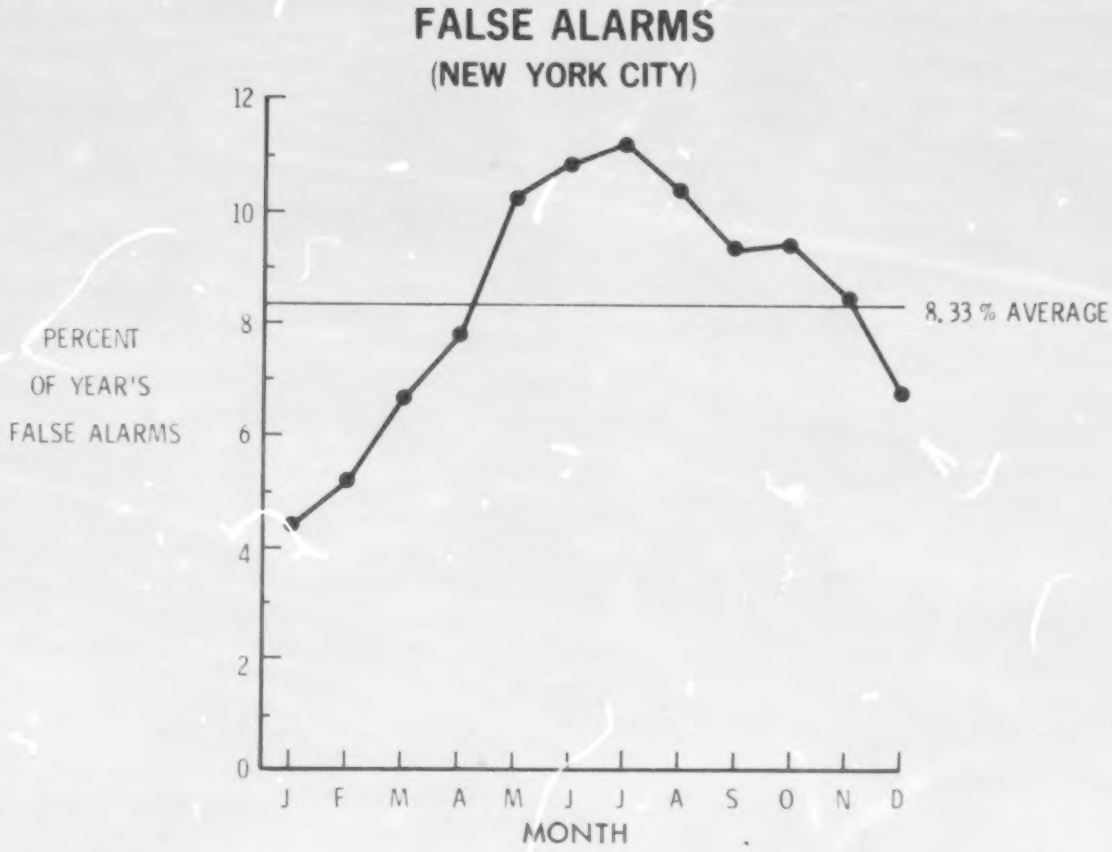

FALSE ALARMS
(NEW YORK CITY)
12
10
8
6
4
2
0
PERCENT
OF YEAR'S
FALSE ALARMS
8.33 % AVERAGE
J
F
M
A
M
J
J
A
S
O
N
D
MONTH

Fig. DF-16

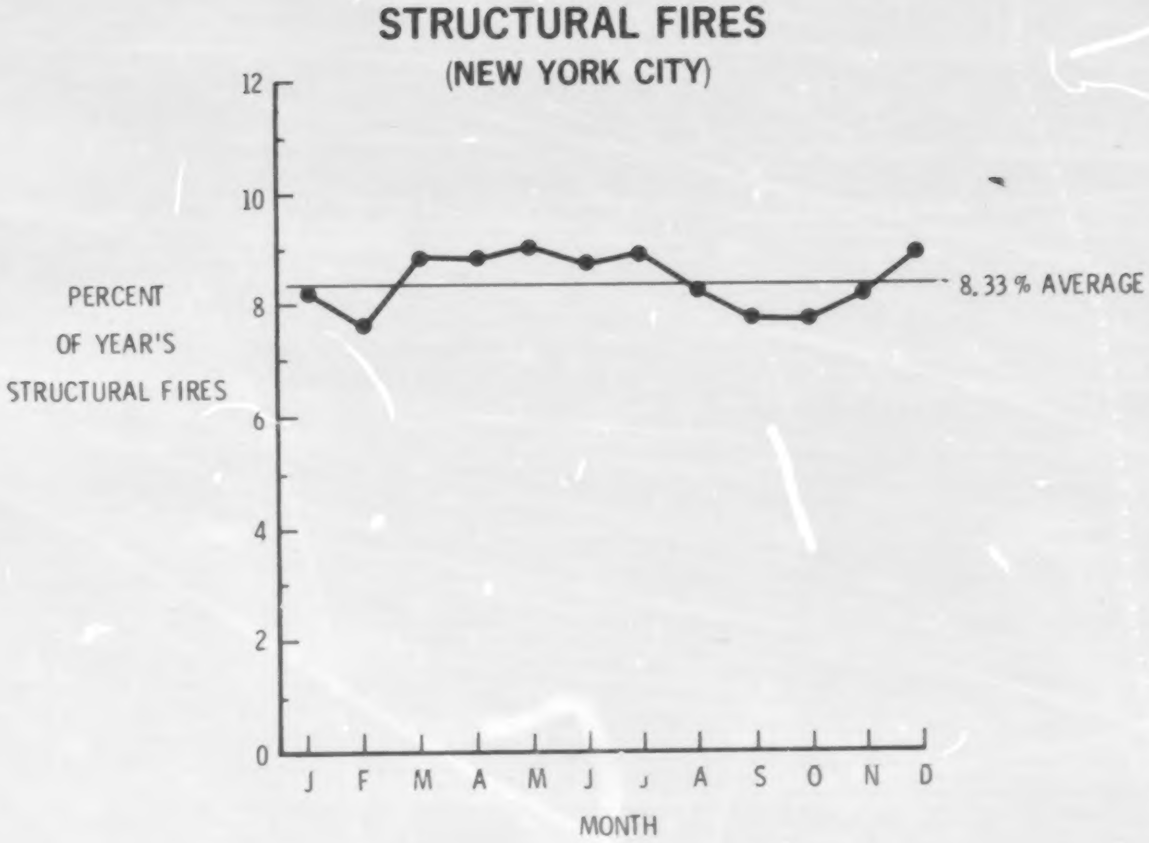

STRUCTURAL FIRES
(NEW YORK CITY)
PERCENT
OF YEAR'S
STRUCTURAL FIRES
12
10
8
6
4
2
0
8.33 % AVERAGE
J
F
M
A
M
J
J
A
S
O
N
D
MONTH

Fig. DF-17

SEASONAL AND TIME OF DAY EFFECTS IN SERIOUS FIRES AS A PROPORTION OF STRUCTURAL

(NEW YORK CITY)

		PERCENT OF ALL STRUCTURAL FIRES IN 1970 REPORTED IN THE INDICATED WAY THAT WORKED MORE THAN ONE LADDER		
		0-8	8-16	16-24
BOX	WINTER	33.8%	28.6%	25.0%
	SPRING-FALL	32.8	25.5	23.1
	SUMMER	32.6	22.0	22.2
PHONE	WINTER	20.9	15.3	11.7
	SPRING-FALL	16.0	11.9	10.3
	SUMMER	16.8	11.5	10.0

Fig. DF-18

PROPORTION OF BOX-REPORTED ALARMS THAT WERE SERIOUS FIRES, BY SEASON AND TIME OF DAY, 1964-1970 BRONX DATA

TIME OF DAY	WINTER PROPORTION	SPRING/FALL PROPORTION	SUMMER PROPORTION	OVER WHOLE YEAR PROPORTION	
0-8 a.m.	0.057	0.042	0.026	0.038	1.7
8 a.m. - 4 p.m.	0.044	0.025	0.018	0.027	1.2
4 p.m. - midnight	0.025	0.015	0.011	0.016	.7
Over Whole Day	0.031	0.021	0.016	0.022	
	1.4	1.0	.7		

Fig. DF-19

SEPARATING SEASONAL AND TIME-OF-DAY EFFECTS: SERIOUS FIRES

	Relative Seriousness: Percent of box alarms in indicated period that were serious ÷ percent of all box alarms that were serious
0 - 8	1.7 = 3.8/2.2
8 - 16	1.2 = 2.7/2.2
16 - 24	.7 = 1.6/2.2
Winter	1.4 = 3.1/2.2
Spring, Fall	1.0 = 2.1/2.2
Summer	.7 = 1.6/2.2

	Actual Percent Serious			Percent Serious if Season and Time-of-Day Effects were Multiplicative		
	Winter	Spring, Fall	Summer	Winter	Spring, Fall	Summer
0 - 8	5.7	4.2	2.6	5.4*	3.6	2.8
8 - 16	4.4	2.5	1.8	3.8	2.5	2.0
16 - 24	2.5	1.5	1.1	2.3	1.5	1.2

*Example: 5.4% = 2.2% x 1.7[0 - 8] x 1.4[winter].

Fig. DF-20

SUMMARY

- DIVIDE THE AVAILABLE DATA IN TWO PARTS
  - Use one for finding patterns
  - Reserve the other for verifying them
- PLOT THE DATA
- MAKE CROSS-TABULATIONS
  - Time of day and season
  - Proportion serious and region
- DIVIDE CITY INTO HOMOGENEOUS REGIONS BY
  - Land use
  - Alarm data
- LOOK FOR USEFUL PATTERNS
- TRY FOR SIMPLE, ECONOMICAL MODELS
- TEST IF THE PATTERNS YOU'VE DISCOVERED ARE CONSISTENT, BY SEEING WHETHER THE RESERVED DATA FITS THEM

Fig. DF-21

LECTURE AF

ALLOCATION OF FIRE COMPANIES

Time: Approx. 60 minutes

Equipment: Computer terminal with telephone coupler (if allocation model is being demonstrated)

Objective: To introduce one approach to analyzing fire company location problems, and to explain the first step in such an analysis.

Activity | References and Notes

1. INTRODUCTION

- What makes it necessary to think about changing the number and location of fire stations?
  - -- Urban renewal
  - -- Neighborhood changes
  - -- Aging of firehouses
  - -- Changes in fire department budget levels
- Must find answers to two questions:
  - (1) How many fire companies are needed?
  - (2) Where should the companies be located?
- In regard to question 1: Why not cost/benefit approach?
  - -- Don't know relationship between dollar losses and travel times
  - -- Requires that a monetary value be placed on human life
  - -- Fire department is only part of the municipal budget. This approach would have to be applied to all agencies
- Practical approach
  - (1) Assume a given budget level--this determines the number of fire companies
  - (2) Find the best way to allocate the companies to regions of the city
  - (3) Find specific sites for each company

Activity	References and Notes

2. ALLOCATION OBJECTIVES

- Hypothetical examples illustrating conflict among objectives
    - -- City has 2 regions of the same size with very different alarm rates
- Allocate to minimize average travel time to alarms
    - -- High travel times in low incidence region
    - -- Ignores fire hazards
- Allocate to equalize coverage
    - -- Companies in high incidence region will have high workloads
    - -- Higher travel times to most alarms
- Conclusion: Neither of these allocations is good

Activity | References and Notes

2. ALLOCATION OBJECTIVES (continued)

- Solution: Use compromise allocation

  -- The Parametric Allocation Model determines allocations for a range of compromises between "minimum average travel time" and "equal coverage"

3. USEFULNESS OF PARAMETRIC ALLOCATION MODEL

- Provides general picture of number of fire companies to allocate to different parts of the city
- Quick and inexpensive to use
- Requires very little data
- Various uses

  -- Compare travel times and workload among regions

  -- Determine reallocations of current resources

  -- Determine regions to gain or lose companies if level of resources is to be changed

4. DATA NEEDED FOR EACH REGION

- City must be divided into hazard regions
- Travel times will be weighted in each region. Weight indicates "importance" of travel time

$$\text{WEIGHT} = \begin{pmatrix} \text{"EFFECTIVE"} \\ \text{ALARM} \\ \text{RATE} \end{pmatrix} \times (\text{HAZARD})$$

Activity | References and Notes

5. WHAT IS "EFFECTIVE" ALARM RATE?

- Each type of alarm is counted in proportion to its seriousness
- If all alarms are considered of equal seriousness, then the effective alarm rate is the same as total alarm rate
- Can count only structural fires, or only fires that required more than a certain amount of work to extinguish (e.g., one company-hour)
- Can weight each type of alarm by the number of company-hours needed to extinguish it. Then

$$\begin{pmatrix}\text{"EFFECTIVE"}\\ \text{ALARM RATE}\end{pmatrix} = \begin{pmatrix}\text{ALARM}\\ \text{RATE}\end{pmatrix} \times \begin{pmatrix}\text{COMPANY-}\\ \text{HOURS}\end{pmatrix}$$

$$= \begin{pmatrix}\text{AVERAGE NUMBER OF}\\ \text{COMPANIES BUSY}\end{pmatrix}$$

6. WHAT IS THE HAZARD FACTOR?

- Subjective measure of the relative danger of a fire (potential for loss of life or property if a fire does occur)
- Suppose the most hazardous region is given a hazard rating of 1.0. Then a region with hazard rating 0.9 is less hazardous to the extent that travel times could be about 10 percent higher in this region, and the department would be willing to say equal quality fire protection is being provided in the two regions
- This is a subjective management input. When using the model, can try several different ways of defining hazards and see what the consequences are

Activity

References and Notes

7. CITYWIDE DATA NEEDED

- "Constant" and "power" in the relationship between travel time and number of companies:

$$\left(\begin{array}{c}\text{AVERAGE TRAVEL}\\ \text{TIME in a region}\end{array}\right) = (\text{CONSTANT}) \times \left(\frac{\text{AREA}}{\begin{array}{c}\text{AV. NUMBER}\\ \text{COMPANIES AVAIL.}\end{array}}\right)^{(\text{POWER})}$$

8. DECISION VARIABLES

- Total number of companies to be allocated to the city
- Tradeoff parameter beta (β). This accomplishes the compromise between "minimum average travel time" and "equal coverage"
    - -- For $\beta = 1$, program shows an allocation that minimizes the average weighted travel time
    - -- For large β (50 or more), program shows an allocation that will make the weighted response time equal in all regions
    - -- [For small β, workload is equalized]
- How does the department choose its desired value of β?
    - -- Try different values between 1 and 50. See what happens
    - -- $\beta = 3$ was found to be "good" in New York City
    - -- It often happens that all values of β indicate that certain hazard regions should lose companies as compared to the present arrangement, and others should gain companies. Such a conclusion is "robust," because any "reasonable" value of β leads to a qualitatively similar conclusion

Activity	References and Notes

9. OUTPUT

- The number of companies to be located in each hazard region
- The average travel time in each region, given the number of companies allocated
- Citywide averages

10. MATHEMATICAL FORMULATION (Optional)

M = total number of companies to be allocated in the city

n_i = number of companies allocated in region i

λ_i = effective alarm rate in region i

h_i = hazard rating for region i

$\tau_i(n_i)$ = average travel time in region i, given n_i companies there

$$= c\left(\frac{A_i}{n_i - b_i}\right)^{\alpha}$$

c and α are the travel-time "constant" and "power"

A_i = area of region i

b_i = average number of companies busy in region i

Optimization problem:

- Minimize $\sum_i \lambda_i (h_i \tau_i(n_i))^{\beta}$

  subject to $\sum_i n_i = M$

- β is the tradeoff parameter

Activity	References and Notes
11. LEAD-IN TO DEMONSTRATION	
• Jersey City will be chosen as an example	
• Display map of city	
• Discuss	
-- definition of demand regions	
-- objective was to plan in terms of alarm rates to be expected in the future	
12. DEMONSTRATION	

Activity	References and Notes

12. DEMONSTRATION (continued)

- Describe "base case" situation

    - -- Discuss response times
        - .. Differences between regions
        - .. Citywide average, noting that it is weighted by regional alarm rates
        - .. Average and percentage busy indicate relative workloads

- Derive allocations for different values of the tradeoff parameter

    - -- Interpret fractional allocations

    - -- Point out that parameter = .25 produces good approximation of current allocation

- Find reallocation for parameter = .25 based on 1983 alarm rates

- Allocations for different numbers of total companies

- [optional] Comparison of different specific allocations with the current situation

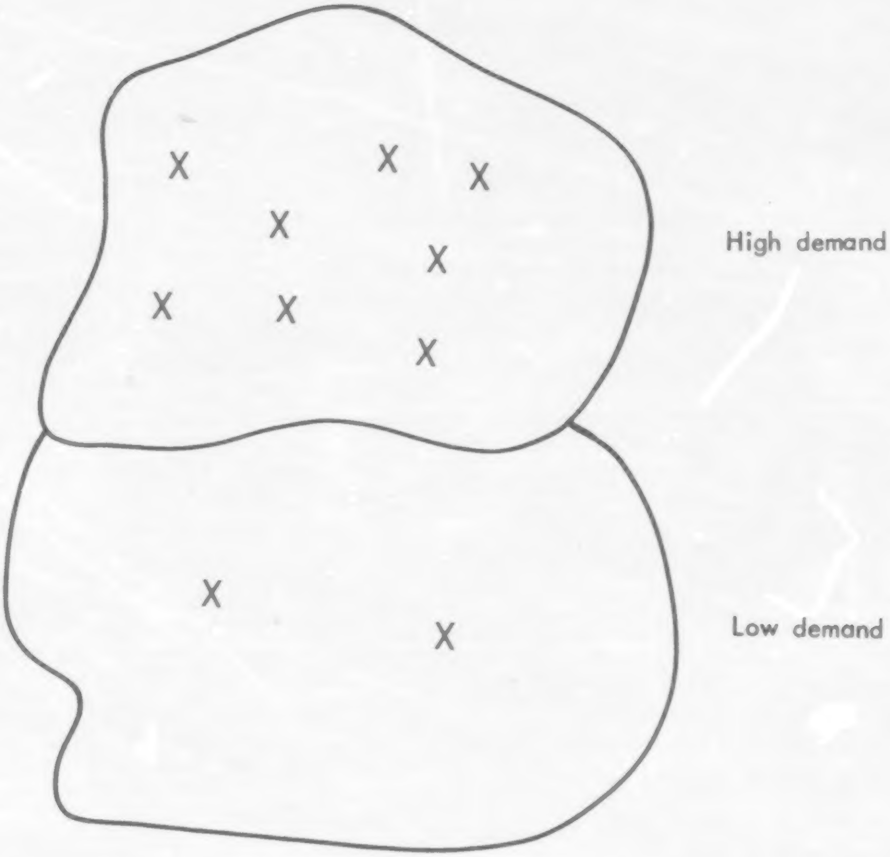

X
X
X
X
X
X
X
X
X
X
High demand
Low demand

Fig. AF-1

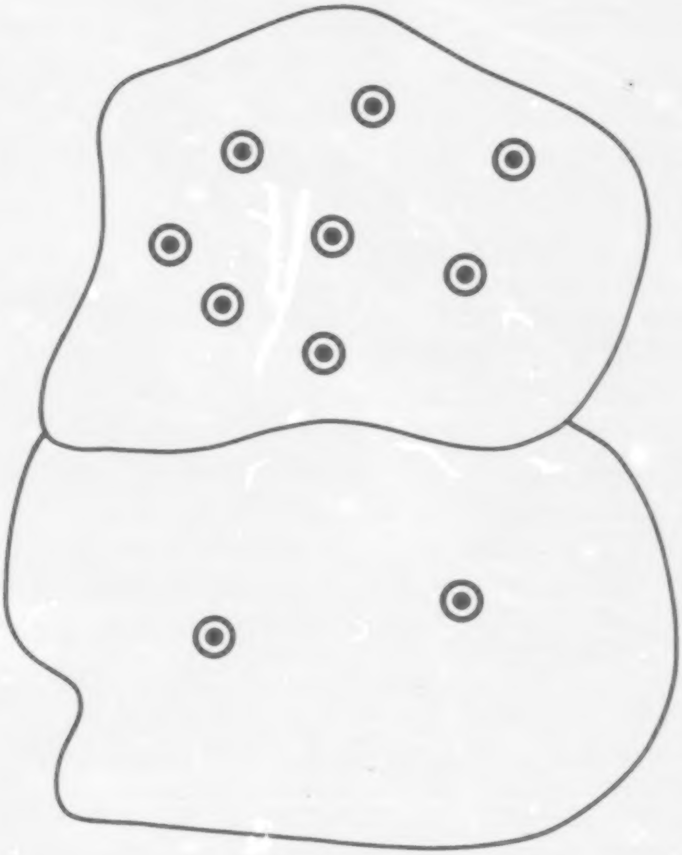


Fig. AF-2—Minimum total response time to all fires

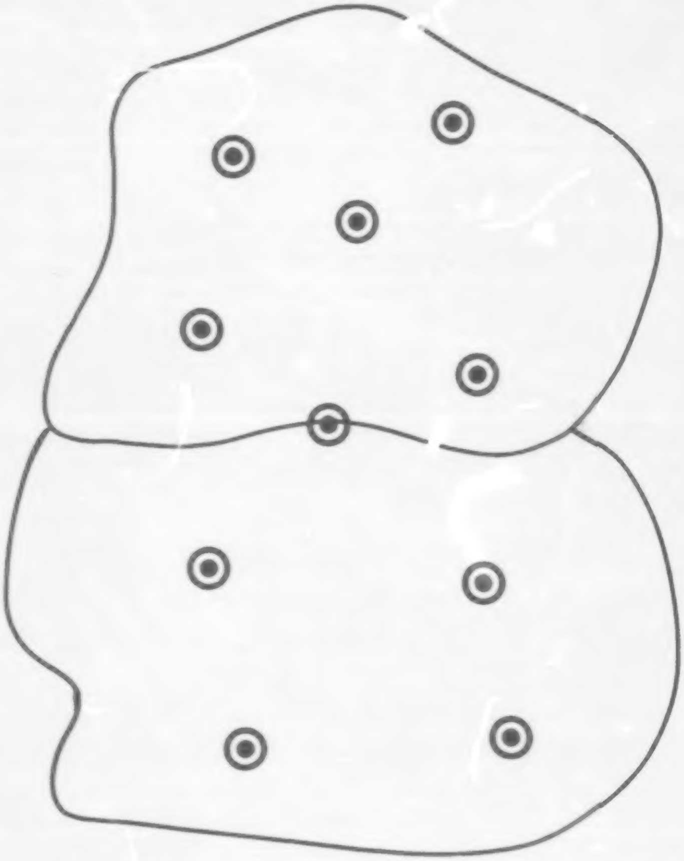


Fig. AF-3 — Equal coverage for both areas

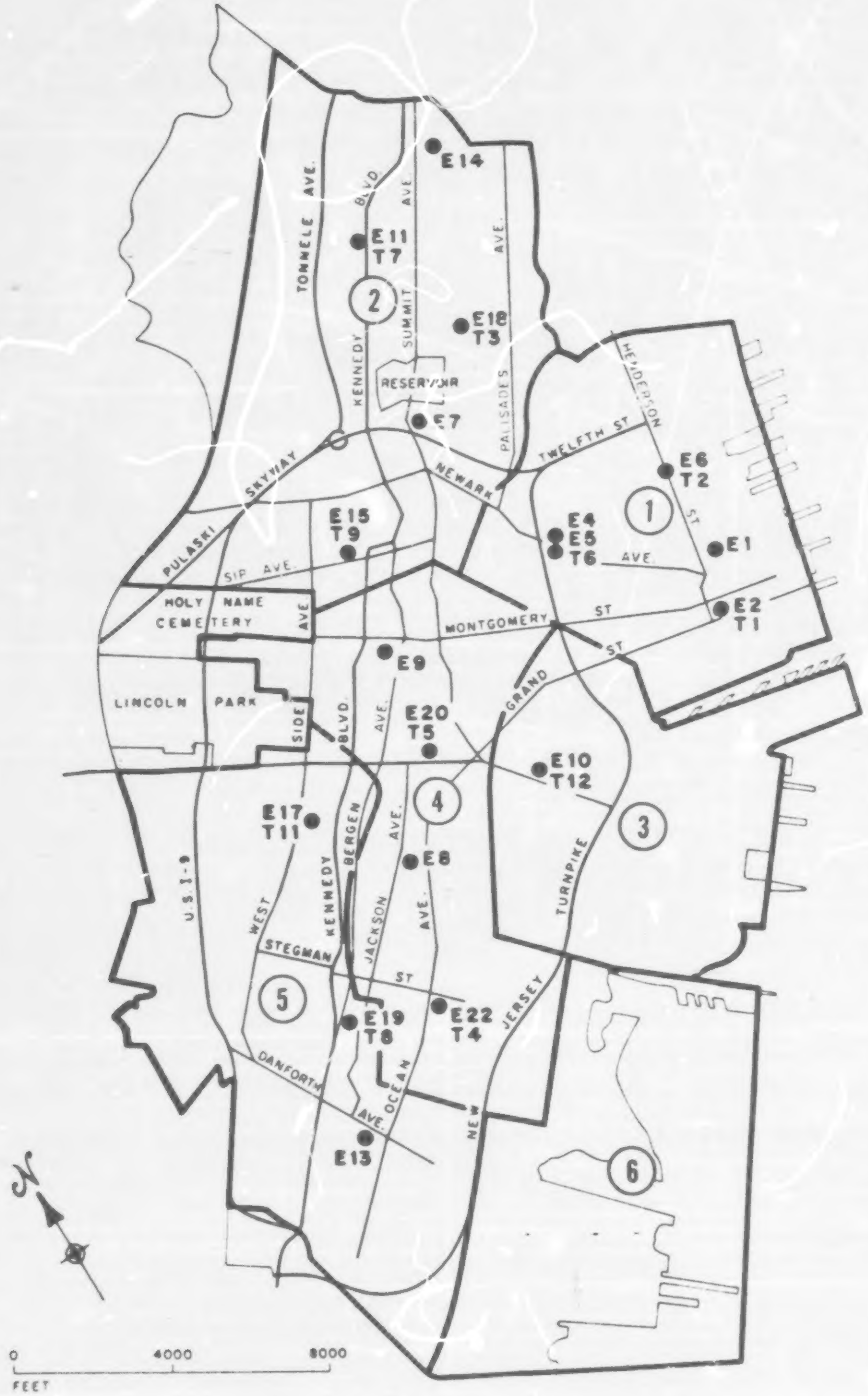

E14
E11
T7
E18
T3
E7
E15
T9
E4
E5
T6
E6
T2
E1
E2
T1
E9
E20
T5
E10
T12
E17
T11
E8
E19
T8
E22
T4
E13
1
2
3
4
5
6
TONNELE AVE.
KENNEDY BLVD
SUMMIT AVE.
PALISADES AVE.
RESERVOIR
HENDERSON ST
TWELFTH ST
NEWARK
PULASKI SKYWAY
SIP AVE.
AVE.
HOLY NAME CEMETERY
AVE
MONTGOMERY ST
ST
GRAND
LINCOLN PARK
WEST SIDE
BLVD.
AVE.
BERGEN AVE.
U.S. 1-9
WEST
KENNEDY
JACKSON AVE.
TURNPIKE
STEGMAN ST
DANFORTH AVE.
OCEAN
NEW JERSEY
N
0
4000
8000
FEET

Fig. AF-4 — Map of demand regions and fire company locations

Demand Region	Name	Area (Sq.Miles)	Population 1970	Population per Sq.Mile (Thousands)	Housing Units	1-2 Family Dwelling Number	1-2 Family Dwelling %	Vacant Units Number	Vacant Units %	Basic Characteristics
1	Downtown	1.52	34,876	22.9	12,512	1,830	14.6	936	7.5	Secondary downtown area, high-rise multiple dwellings, waterfront
2	Hudson Heights	2.82	82,060	29.1	30,447	11,965	39.3	1,050	3.4	Primary downtown area, semidense residential
3	Lafayette Liberty Harbor	0.85	11,721	13.8	3,857	954	24.7	245	6.4	Mainly industrial, some residences
4	Bergen	1.98	76,019	38.4	26,589	12,651	47.6	1,390	5.2	Dense residential area, small businesses
5	Westside Greenville	2.59	54,937	21.2	18,339	10,806	58.9	474	2.3	Less dense residential, some industry
City-wide		9.76	259,613	26.6	91,744	38,206	41.6	4,095	4.5	

Fig. AF-5 — Demand region demography

Demand Region	Number		Alarms/Sq.Mile		Alarms/Capita		Fires in Residences		
	Total	Structural	Total	Structural	Total	Structural	Number	% of All Structural	Per Capita
1	3,308	395	2,176	260	.0949	.0113	305	74.6	.0088
2	2,459	390	872	138	.0300	.0048	326	81.5	.0040
3	838	113	986	133	.0715	.0096	110	79.1	.0094
4	3,366	840	1,700	424	.0442	.0111	698	89.0	.0092
5	1,599	279	617	108	.0291	.0051	244	84.1	.0044
City-wide[a]	11,570	2,017	1,185	207	.0446	.0078	1,683	83.2	.0065

[a] Excluding Region 6.

Fig. AF-6 — Demand region alarm incidence

Region	Area Sq.Miles	Alarms per Hour 4 p.m. to Midnight			
		All	False	Nonserious Structural	Serious Structural
1	1.52	.722	.403	.040	.015
2	2.82	.444	.137	.047	.009
3	0.85	.202	.088	.027	.003
4	1.98	.630	.290	.094	.013
5	2.59	.330	.127	.039	.007

Fig. AF-7 — 1972-1973 alarm rates

LECTURE LF

LOCATING FIRE STATIONS

Time: Approx. 70 minutes including demonstration of program

Objective: To discuss the general problem of locating fire stations, and to compare two specific approaches to the problem.

Equipment: Portable terminal with acoustic coupler for demonstration.

Activity	References and Notes
1. INTRODUCTION • Topic is evaluation of current fire station sites, and planning which ones to close and/or where to put new ones • Discussion may be followed by demonstration • NYCRI treats this question in two stages: (a) Obtain ideas and insights from the allocation model (b) Use a descriptive model to evaluate specific configurations • Other approaches perform analyses in one stage	

Activity	References and Notes
2. GENERAL APPROACHES	
• Minimize sum of fire department costs and expected fire losses (including fatalities). A worthy objective; some studies have been done along these lines in Great Britain. Problem: No generally useful way has been found to estimate fire losses from response times	
• Minimum average response time. May not be a good idea, as tends to indicate greatest need for stations in high-alarm areas while ignoring low-fire areas. When choosing among otherwise equally satisfactory configurations, may be useful	
• Coverage. Each potential fire site should be within reasonable distance (or time) of a fire station. Easy to apply, but too simplistic and based on subjective judgments	

Activity | References and Notes

3. MEASURES FOR EVALUATING ALTERNATIVES

- Use surrogate measures for fire loss. Give decisionmaker information on how a given configuration will perform using several measures of fire protection
  - -- One configuration will probably not dominate another configuration on all measures
  - -- Administrators must subjectively balance the measures; they will also add judgments concerning hazards and political constraints
- Primary considerations:
  - -- Travel times. Make sure that each potential fire site is within a reasonable time from a firehouse
  - -- Hazards. Want to single out some potential fires as more important than others for achieving rapid response
  - -- Average regional travel times. Useful for evaluating relative fire protection in different areas of a city
  - -- Fire company workload. May want to balance workload over companies. Most important when workload is high

Activity | References and Notes

4. GENERAL DATA REQUIREMENTS

- Geographic division
    - Divide city into small subareas, as small as the area covered by a single alarm box (real or phantom), perhaps four or five times this size
    - Assume all demand for fire service in the subarea arises at one point. Estimates of travel times to any point in the subarea will be the same as to that point
    - Find historical (or expected future) fire incidence in each subarea
- Identify points at which construction of a firehouse is feasible. Failure to do this will lead to consideration of options that are infeasible and impractical
- Identify those subareas having special hazards
    - Analysis will pay special attention to these subareas
- Must have some method for estimating travel time from any firehouse (existing or proposed) to any subarea
- Obtain estimates of capital construction costs; and current costs of depreciation, operation, and maintenance of existing stations

Activity | References and Notes

5. ESTIMATING TRAVEL TIMES

- Method 1. Developed by Public Technology, Inc. (PTI)

  -- Describe street network of city in computer-readable form. Street intersections are identified as nodes in the network, streets are represented as connecting links between nodes. Not necessary to consider all streets; main arterials are adequate

  -- Estimate average travel speed on each link. This may be done from experienced guesses, traffic surveys, experimental trips by fire companies, or from previously collected response-time data

  -- Estimate time to travel over each link using speed and distance

  -- Subareas are called fire demand zones; the point representing all the properties in a fire demand zone is called a focal point

  -- Every potential or existing firehouse and every focal point is referenced to a node of the street network

  -- The travel time from a firehouse to a focal point is estimated by finding the set of connecting arcs that form the minimum time path

Activity	References and Notes

5. ESTIMATING TRAVEL TIMES (continued)

- Method 2. Developed by NYCRI

  -- Run a "travel-time experiment" showing origin and destination for each response by fire companies, odometer distance traveled, and the time required for the response

  Data can be collected in the units, or at the dispatch center if units radio in when departing and arriving

  -- Fit a smooth curve to data showing actual travel time versus distance

  (a) In some cities, straight line with positive intercept provides best fit

  (b) In most, a blend between straight line and a square-root curve is best

  (c) Curve may vary in different parts of the city and at different times of day. But experience has shown that neither effect is large, and that approximately the same curve can be used for any city at all times of day

  -- Determine x-y coordinates of existing and potential fire station sites on a grid map of the city. Determine x-y coordinates for the subareas in which incidence will be estimated

  -- Estimate distance from stations to subareas in some way, e.g., as sum of x and y distance traveled (right-angle distance) or a modification of straight-line (Euclidean) distance

  -- Parameters of fit curve are used to estimate travel time between any two points, using estimated distance

Activity

References and Notes

5. ESTIMATING TRAVEL TIMES (continued)

- Relative advantages of Method 1
    - -- If road network has already been developed (by traffic department, for example), this is fastest way to proceed
    - -- Road network, when developed, may be useful to other city agencies
    - -- Barriers to travel (hills, railroad tracks, rivers, airports) are automatically taken into account
    - -- Effects of changes in structure of road network can be analyzed in advance (new interstate highway, new bridge, closing of existing bridge)
    - -- Irregularly shaped areas (peninsulas, or cities with holes in them, for example) are automatically handled accurately
    - -- Fire officials may feel more comfortable with a method that actually imitates the path followed by fire companies, whether or not method is actually accurate
- Relative advantages of Method 2
    - -- Elaborate data base and computer program not needed; lower cost for analysis
    - -- If road network has not already been developed, this method is significantly faster
    - -- If travel times have already been collected (e.g., by UFIRS), this method is very fast
    - -- Parameters for fit curve have been so close to the same values for many cities that it may be possible to proceed without collecting any travel-time data
    - -- Method has been validated against actual travel-time data and has been found accurate enough for site selection
    - -- In case of irregularly shaped areas, ad hoc adjustments to method are easily accomplished
- The travel-time estimates produced by Methods 1 and 2 have never been directly compared

Activity	References and Notes

6. GENERATING POSSIBLE SITE CONFIGURATIONS TO EVALUATE

- Method 1. Developed by PTI
  - -- Still in developmental stage; requires PTI's assistance
  - -- A maximum travel time is specified for each focal point
  - -- A set of existing and potential firehouse sites is specified
  - -- A computer program determines whether any collection of potential station locations can meet the travel-time requirements. If so, it prints out a solution that requires the smallest possible number of sites
- Advantages of Method 1
  - -- Procedure is very well defined. Documentation provides step-by-step guide to the tasks that must be carried out to use the program and provides forms for collecting and organizing required data
  - -- Method is potentially very powerful. If maximum travel times can be determined, can generate, among the large number of possible configurations, the one that meets all requirements with the fewest number of fire companies

Activity	References and Notes
6. GENERATING POSSIBLE SITE CONFIGURATIONS TO EVALUATE (continued)	

- Difficulties with Method 1
  - -- No accepted standards for travel-time constraints
  - -- Once fire officials agree on a set of requirements, the resulting number of stations needed may exceed any reasonably foreseeable budget. Constraints must then be relaxed
  - -- Travel-time requirements corresponding to existing number of stations may be hard to determine
  - -- PTI program may fail to operate, leading to no solution
  - -- Recommended station configuration may involve moving many stations, while another equally acceptable configuration (not known) involves moving fewer stations. Other acceptable solutions (also not known) may be preferable in regard to average travel time or other characteristics
- Method 1M. Modification developed by University of Colorado
  - -- Same approach as PTI's
  - -- Computer program finds a configuration that meets the requirements and has the minimal number of stations. This configuration includes the largest possible number of existing station sites

Activity	References and Notes

6. GENERATING POSSIBLE SITE CONFIGURATIONS TO EVALUATE (continued)

- Method 2. Used by NYCRI
    - -- Use allocation model to determine demand regions needing more or fewer stations
    - -- From a map of the city showing existing and potential sites, select several possible configurations that approximately match desired allocations by region
    - -- Use siting model (to be described next) to compare the trial configurations. Develop improved trial configurations by looking at the results for others
- Virtues and difficulties with Method 2
    - -- Easy to use; fast to implement
    - -- Process of choosing configurations requires judgment and "map sense"
    - -- May overlook good configurations

Activity	References and Notes

7. EVALUATING TRIAL CONFIGURATIONS

NYCRI has a "Firehouse Site Evaluation Model" that calculates a set of descriptive measures for any pair of configurations. Other researchers have similar computer programs, differing only in details

(a) Calculations are based on a number of assumptions

- All units are always available in their firehouses to respond to an incoming alarm (reasonable assumption for most cities)
- The closest units are always dispatched to an alarm
- Calculations are performed separately for each type of fire-fighting equipment
- Travel distances are estimated by right-angle or "modified" Euclidean distance
- Travel times are estimated from empirically determined curve

Activity	References and Notes

7. EVALUATING TRIAL CONFIGURATIONS (continued)

(b) Performance measures

- For each demand region, citywide, identified target hazards, and/or region affected by change: average travel time and average travel distance
    - -- weighted by expected incidence and unweighted (each subarea given equal weight)
    - -- first-due, second-due, third-due, etc.
- Frequency distribution of travel times for each demand region and citywide
- For each company's first-due response area: average travel time, maximum travel time (to farthest subarea), workload (incidents/year), and a list of the subareas (alarm boxes) that constitute the response area (this information is also available for second-due areas, etc.)
- Travel time and travel distance to each subarea (alarm box) identified as a target hazard
- A list of the subareas whose first-due travel times are improved by the change, and those whose first-due travel times are worse, plus the alarm incidence at each group of boxes and average travel times within each group, both before and after the change

Activity	References and Notes

8. DATA REQUIREMENTS FOR FIREHOUSE SITE EVALUATION MODEL
(Aside from general data requirements described earlier)

- List of subareas containing target hazards
  - Purpose: to have program specifically indicate the travel times to these subareas
  - Effect of changes in travel times to these subareas is important
- (x-y) coordinates for every subarea, existing station, and potential station
- A list of subareas included in each company's current response areas
- Parameters of the curve relating travel time to travel distance

Activity | References and Notes

9. DEMONSTRATION OF MODEL

- Be sure to make some change in station locations before running program. Otherwise the "old" and "new" columns will be the same, and there will be no "affected region"

- Preferably, the changes should not be elaborate; the point is not to show what the biggest possible performance change would be in one city. Suitable tests are:

  -- Trenton engines

```
M E3-8431
M E1-2232
M E8-2432
O C=(E)
```

  -- Trenton ladders

```
M L1-2232
O C=(L)
   or
M L1-2432
O C=(L)
```

Activity	References and Notes

9. DEMONSTRATION OF MODEL (continued)

- Command language

  (E can be replaced by L)

  M Enn-mmmm

  Move engine nn to subarea or box mmmm
  [e.g., M E10-2104]

  D Enn

  Delete engine nn
  [e.g., A E12-3510]

  A E-mmmm

  Add an engine at box mmmm

  C*

  Clear stack of commands

  Cn

  Clear last n commands

  O C=(E,L); D=1 or n; L=Y or N;
  W=S or A; R=(C,D,A,T)

  (all on one line; start with letter O; defaults are underlined; use parentheses as shown)

  C - company type: engines or ladders or both

  D - response level: up to nth-due

  L - box listings, Yes or No

  W - weight by structural (S) or all alarms (A)

  R - which regions to produce output for

  C - by Company

  D - by Demand region

  A - for Affected region

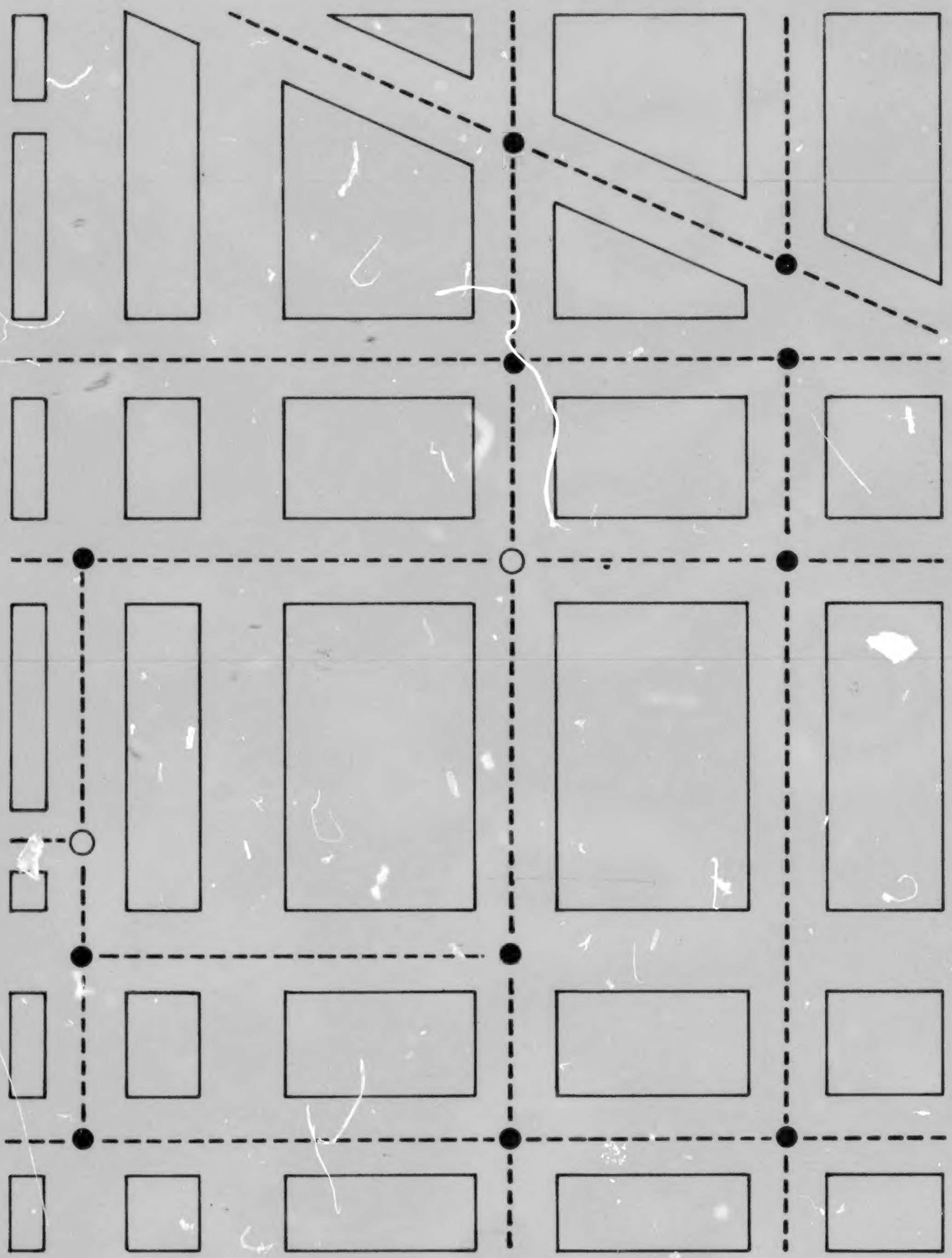
  T - Target hazards

  E

  Exit from program

- Siting model prints results side-by-side for "current" and "proposed" configurations

  -- Facilities comparisons



Legend: Circles represent nodes at street intersections. Not all streets are represented in the network.

Fig. LF-1 — Street network concept: nodes and links

Company: ____________

Codes:

Weather condition D = dry
W = wet

Traffic condition L = light
M = moderate
H = heavy

Usual route followed U = usual
D = detour

Due 1E = first engine
2L = second ladder

Odometer before responding				Odometer before returning				Duration of run				Alarm box number				Time out						Weather condition	Traffic condition	Due		Usual route followed
								min.		sec.						Hr.		Min.		AM PM						
1	2	3	4	1	2	5	2	0	3	1	2	0	2	2	1	0	6	5	1	A	M	W	L	1	E	U
3	5	9	0	3	6	0	7	0	1	0	3	0	1	7	2	1	2	1	3	P	M	D	M	2	L	D
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Fig. LF-2—Sample data form for travel-time experiment

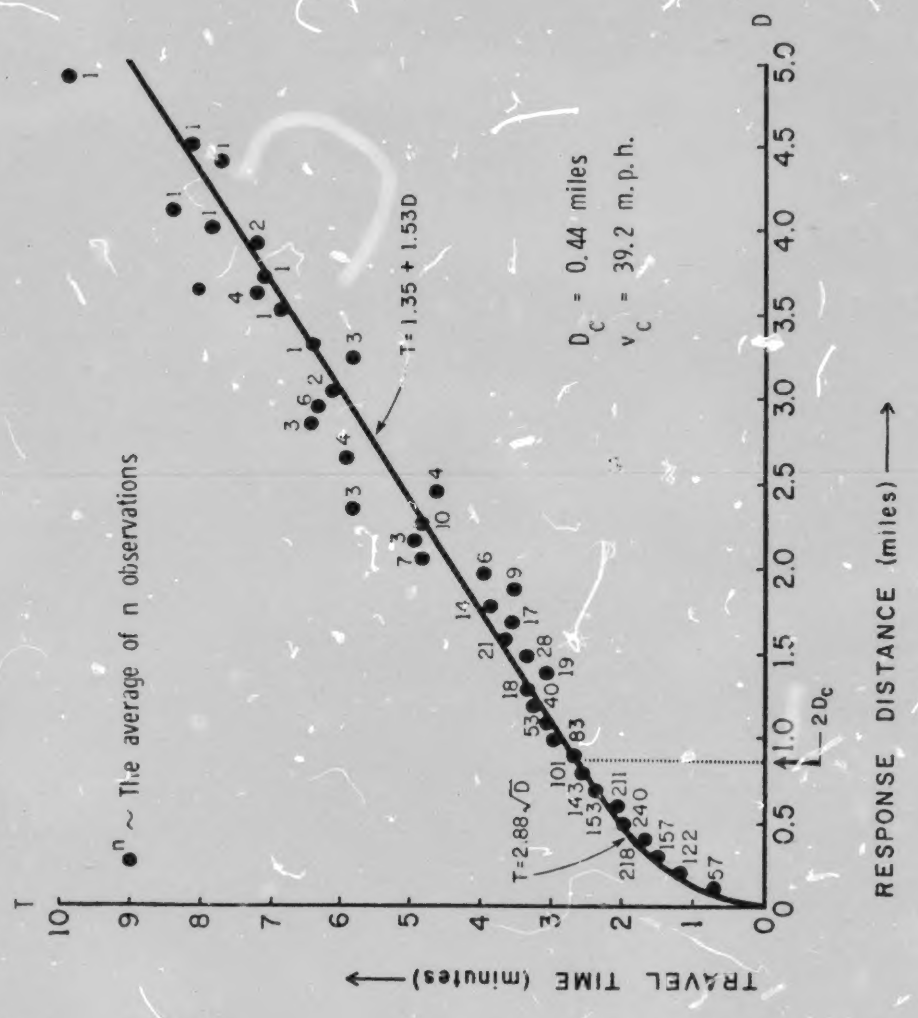


Fig. LF-3—Graph of travel time versus response distance for New York City

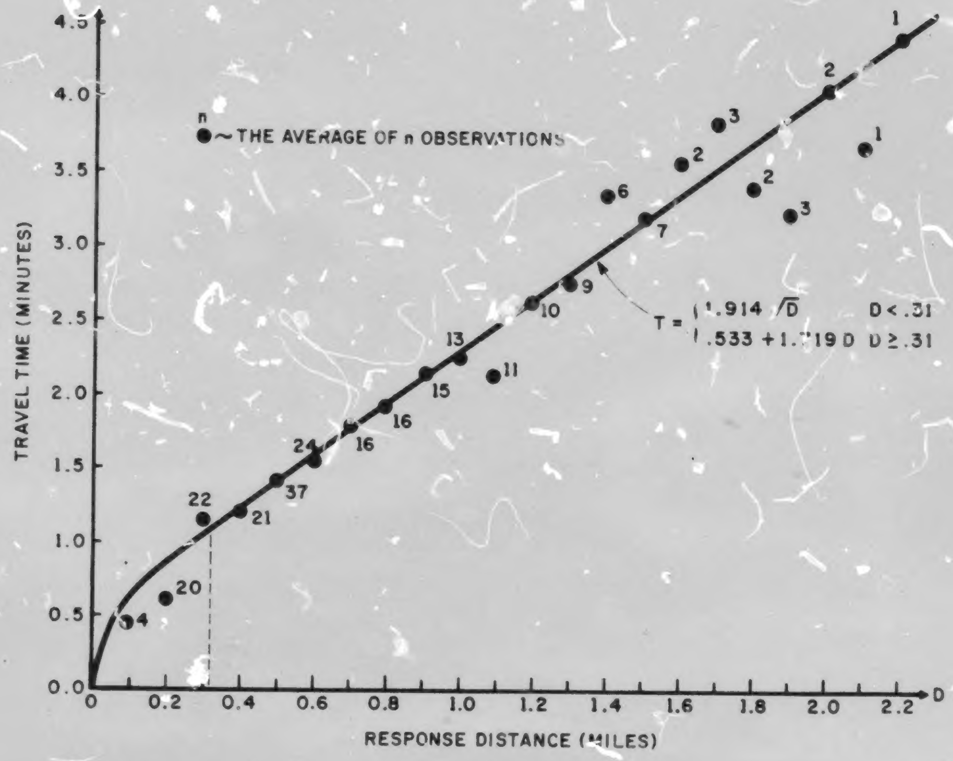


Fig. LF-4 — Graph of travel time versus response distance for Trenton, New Jersey

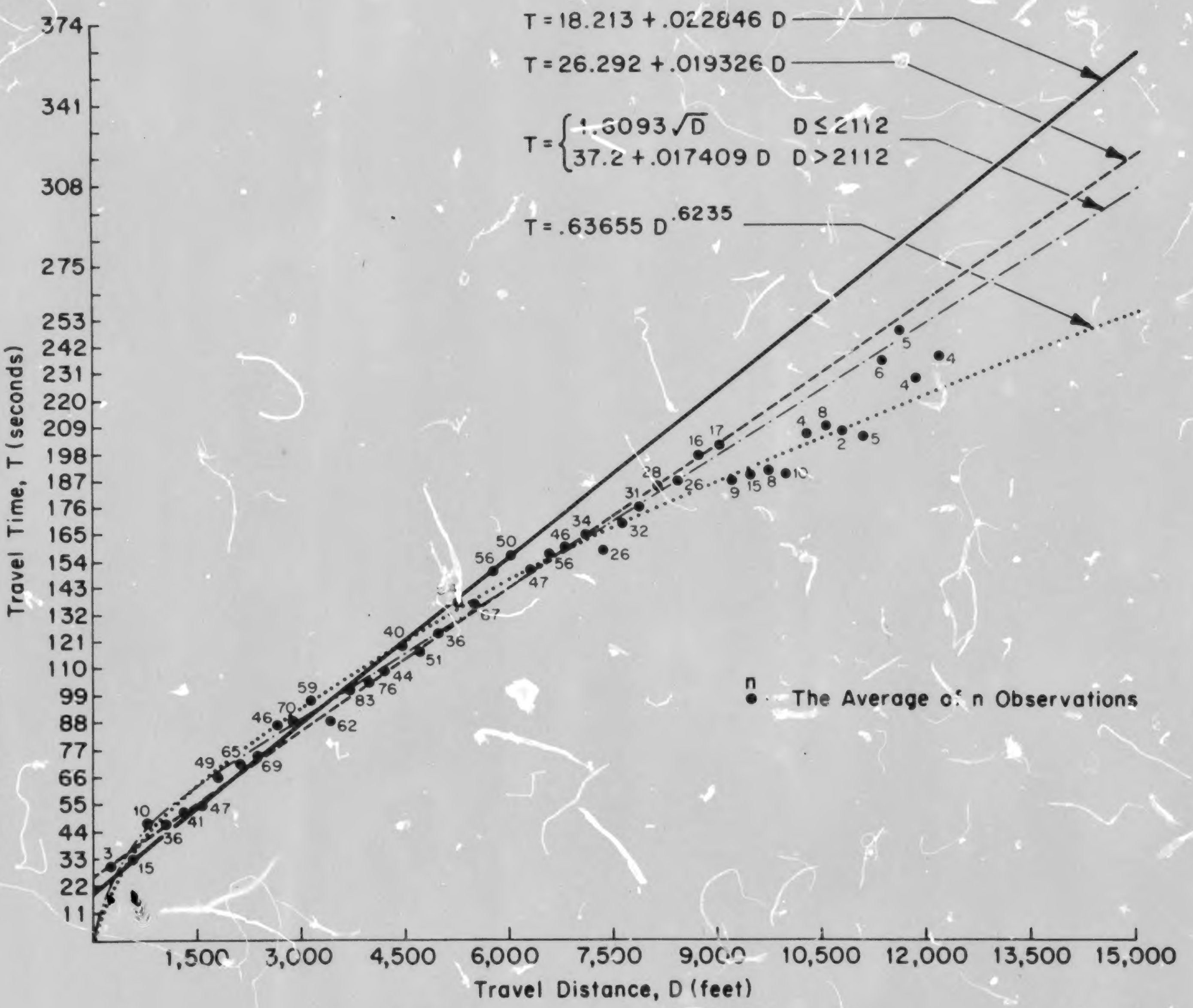


Fig. LF-5 — Graph of travel time versus response distance for Denver, Colorado

LECTURE SF

SIMULATION
FOR FIRE SERVICE AUDIENCES

Time: Approx. 50 minutes

Objective: To describe what a simulation model does, what kinds of questions it can answer, when to use it, and what resources are needed to use it.

Activity	References and Notes
1. DEFINITION	

- Follow each incident step-by-step:

  From occurrence
  - to report to fire department
  - to dispatch of companies
  - to their arrival at scene and work there
  - to their return to availability

- Do this for a large number of incidents
  - actual incidents, or
  - imaginary incidents generated by the computer to match average statistics for alarm rates, etc.

- Viewpoint of an "all-knowing" dispatcher who keeps track of the location of all incidents and companies at all times, but is not concerned with fire-fighting tactics at the scene

- Computer collects statistics on response times, coverage, workloads

Activity	References and Notes
2. WHY SIMULATE?	
• Accuracy compared to other models (at a price) -- Removes approximations present in every simple model -- Accounts for interrelationship among policies that can be individually studied with simple models	
• Safety as opposed to real-world test -- No operational or capital investment -- No lives or property risked -- The model can imagine that alarm rates "stay the same" after policy changes, but in the real world alarm rates will change	
3. DRAWBACKS	
• Simulation is expensive to run on the computer	
• Extensive data collection needed	
• Simulation does not suggest any particular policy as desirable	
• User must be technically skilled	

Activity	References and Notes

4. WHEN TO USE A SIMULATION MODEL

- Detailed comparison of complicated deployment policies
    - -- Number of companies on duty
    - -- Where located
    - -- Number of units dispatched to particular types of alarms
    - -- Which unit(s) dispatched
    - -- When units are relocated (moved up)
    - -- Which units are moved and where they go
- Validation of simpler models, which are
    - -- Cheaper to use
    - -- Easier to interpret
- Instill confidence in administrators that final recommendations will work as planned, especially under adverse circumstances

5. WHERE DO THE POLICIES COME FROM, TO TEST ON A SIMULATION MODEL?

- Fire department administrators
- Planning personnel
- Simpler models

Activity	References and Notes

6. HOW DOES THE NYCRI SIMULATION MODEL WORK?
    - Discuss flow chart

7. WHAT INFORMATION IS IN THE SIMULATION OUTPUT
    - Response times
        - -- Average and distribution
        - -- By incident type
        - -- By geography
    - Company workloads
        - -- Total
        - -- By company
    - Coverage

8. DATA AND RESOURCES NEEDED

- Geographical representation of the part of the city to be simulated
    - -- Incident locations
    - -- Company locations
- Parameters for estimating travel time of every response
- Work times at different types of incidents
- An input stream of incidents
    - -- Actual incidents from the past
    - -- or, incidents generated from detailed data about alarm rates by type and location
- Deployment policy
    - -- Detailed decision rules for dispatching and relocation
- Access to a SIMSCRIPT I.5 compiler
- Analysts who can modify the computer program and interpret the output

9. VALIDITY (Optional)

- Detail and structure have to be sufficient to support insights and conclusions
- What matters is the accuracy of comparisons, not faithfulness to the real world

  Example: If all travel times are 10 percent high, this should not make any difference. (On the other hand, it would be easy to fix)

Activity	References and Notes
10. RECAP	

- Computer's job: do the bookkeeping
- User's job
    - -- Build model: specify how the system works
    - -- Analyze data: specify the kind of data needed (and get it)
    - -- Select criteria: specify what is to be measured
    - -- Find alternatives: specify the policies to be tried out in the simulation

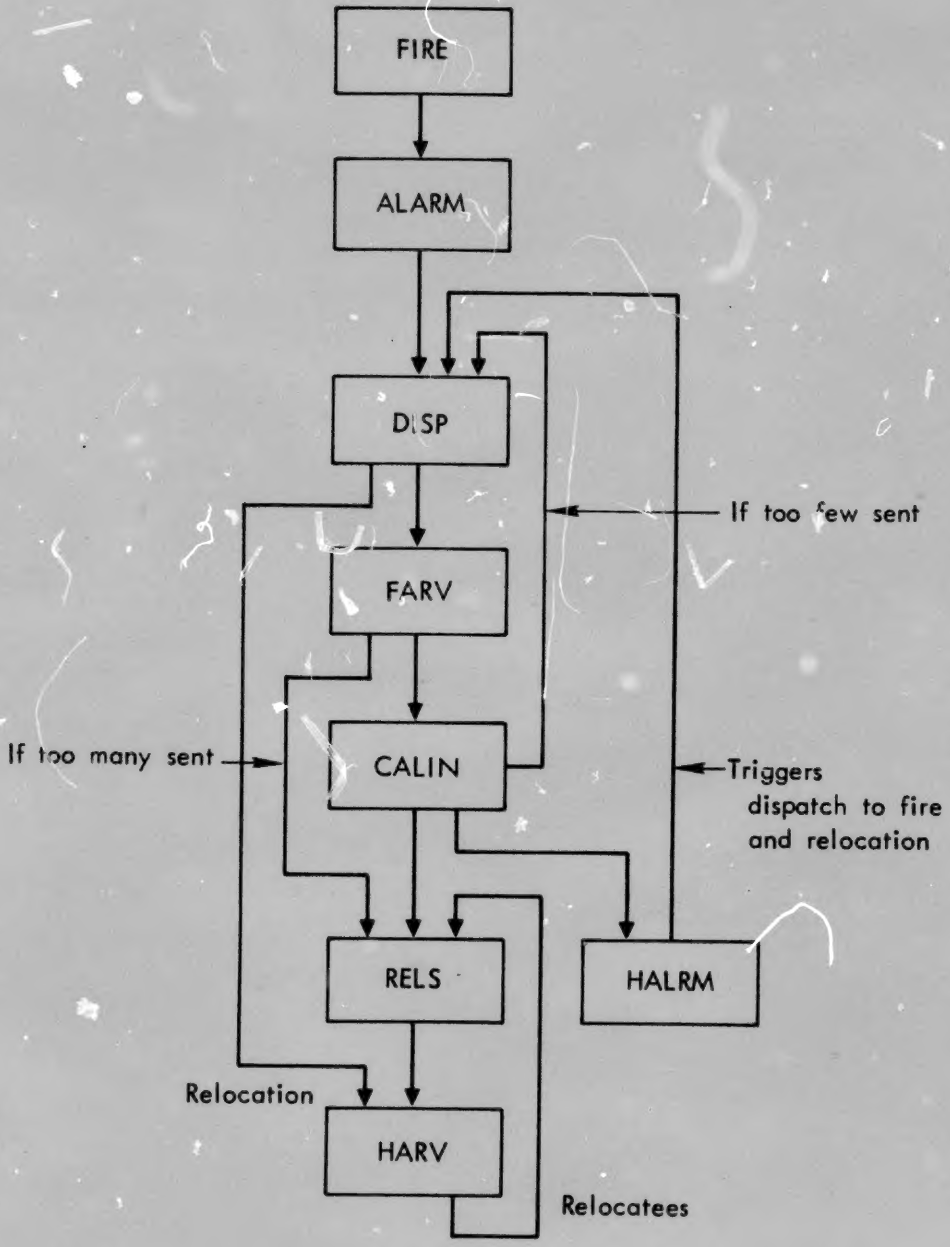

FIRE
ALARM
DISP
If too few sent
FARV
If too many sent
CALIN
Triggers dispatch to fire and relocation
RELS
HALRM
Relocation
HARV
Relocatees

Fig. SF-1

LECTURE MF

RELOCATION OR MOVE-UP
FOR FIRE SERVICE AUDIENCES

Time: Approx. 40 minutes (demonstration extra)

Objective: To indicate difficulties with a system of preplanned relocations and demonstrate a method for resolving the difficulties.

Equipment: Portable terminal with acoustic coupler for demonstration.

Activity	References and Notes
1. INTRODUCTION: RELOCATION ISSUES	
• When should fire companies relocate (move up)?	
• How many should relocate?	
• Which ones?	
• To where?	
2. PREPLANNED RELOCATIONS	
• Problems at high alarm rates	
-- Several "all hands" fires in one part of the city can create a "hole" in coverage as big as if there were one second-alarm or third-alarm fire	
-- Company designated to relocate may already be busy at a fire	
-- Company designated to relocate may be available, but moving it would create another big hole in coverage	

Activity | References and Notes

3. NYCRI APPROACH

- Answer the four questions posed in the Introduction, one at a time

- Separate (but same) calculations for engines and ladders (will use ladders as an example)

Question 1: When should fire companies relocate?

Answer: Relocate whenever some location in city has both its first-due and second-due ladders unavailable, and they will be unavailable for a period of time

-- Define a ladder response neighborhood (RN) as all points in the city having the same first- and second-due ladders, independent of order

-- If both are unavailable, and will be for awhile, the RN is "uncovered"

-- Result: Relocate whenever there is an uncovered RN in the city

-- This criterion maintains relative spacing of fire companies throughout the city (denser in some regions than others)

Question 2: How many should relocate?

Answer: If there are any uncovered RNs. fill the minimum number of houses needed to remedy the situation

Activity	References and Notes

3. NYCRI APPROACH (continued)

Question 3: Which companies should move?

Answer: Choose companies to satisfy four general principles

(a) Don't relocate a company that will create a new uncovered RN

(b) Don't relocate a company that is "too busy"

- First-due areas the same size
  More alarms around #2
  Same distance to X

-- If move #1, second-due unit will be the first-arriving unit in the first-due area of #1

-- Similar if move #2

-- More likely to have a fire near #2

-- Therefore, prefer to move #1

(c) Don't relocate a company that is covering too large a region

- First-due area of #1 larger
  Same number of alarms in both
  Same distance to X

-- Average first-due travel time already higher area of #1

-- If move #1, average travel time for second-due company to respond to region #1 will be much higher than in region #2

-- Prefer to move #2

3. NYCRI APPROACH (continued)

Question 3 (continued)

(d) Don't relocate a company "too far"

- First-due areas of #1 and #2 the same size
  Same alarm rate
  #2 is farther

-- If relocated, #2 would be out of its region longer than #1 would be

-- Therefore, chance of missing an alarm in its region would be higher for #2 than for #1

-- Prefer to move #1

Note: Real cases are a mixture of different alarm rates, different sized areas, and different relocation distances. Developed a "cost" function that blends all these things

- Represents the expected average travel time for first-arriving unit to alarms in the area affected by the moves (areas whose first-due travel times will be changed) during the duration of the moves
- Objective: Choose units to move that minimize this "cost"
- Note: The cost function assumes that while the companies are relocating they are not protecting either their own area or their destination area

Question 4: Where do the companies move?

Answer: Assign relocating companies to the houses being filled so as to minimize the total travel time of the relocating companies

- "Cost" will be higher than minimum, but only slightly
- Relocations will "look better"

Activity

References and Notes

4. DATA NEEDED

(a) For each firehouse

- Number and identity of units stationed there
- List of RNs associated with each of the companies
- Size of each first-due area, in square miles
- Alarm rate in each first-due area

(b) For each RN

- Size of area in which each of the two units is first-due
- Alarm rate in each of the two areas

(c) For each pair of houses

- Travel time from one to the other

(d) Parameters for relating travel time and area, so that travel times in each region can be estimated from their areas

5. APPLICABILITY

- Method requires a real-time computer to make calculation based on the actual status of all fire companies
- Method can be used to generate relocations to be specified on running cards, in which case it is not operated in real time. (But not all situations requiring a relocation are handled well by running cards)

Activity | References and Notes

6. DEMONSTRATION OF ON-LINE RELOCATION PROGRAM SCENARIO 1

This demonstration compares manually developed relocations with what the program does, revealing that neither way is perfect. Geography corresponds to the borough of the Bronx in New York City

```
MICS

M=NOVERIFY
E=MNE,MNL,QNE,QNL

1:R=E63,E62,L39,L32
S=1

(CR)

2:S=E38,E79,E48,E97,L51

C=EW,LW

DEP2P:D=EW,LW




3:S=E75,E90,E81,L46


C=EW,LW



Q=3
U=DEP2P

DEP2C:D=E81,QE63;E43,QE62;E50,QE79;E89,QE97;
  L46,QL39;L50,QL51

(CR)

3C:S=E75,E90,E88,L37
C=EW,LW


/*
```

Activity	References and Notes
7. SCENARIO 2	
• Invent a sequence of small fires that leads to a need for relocation	

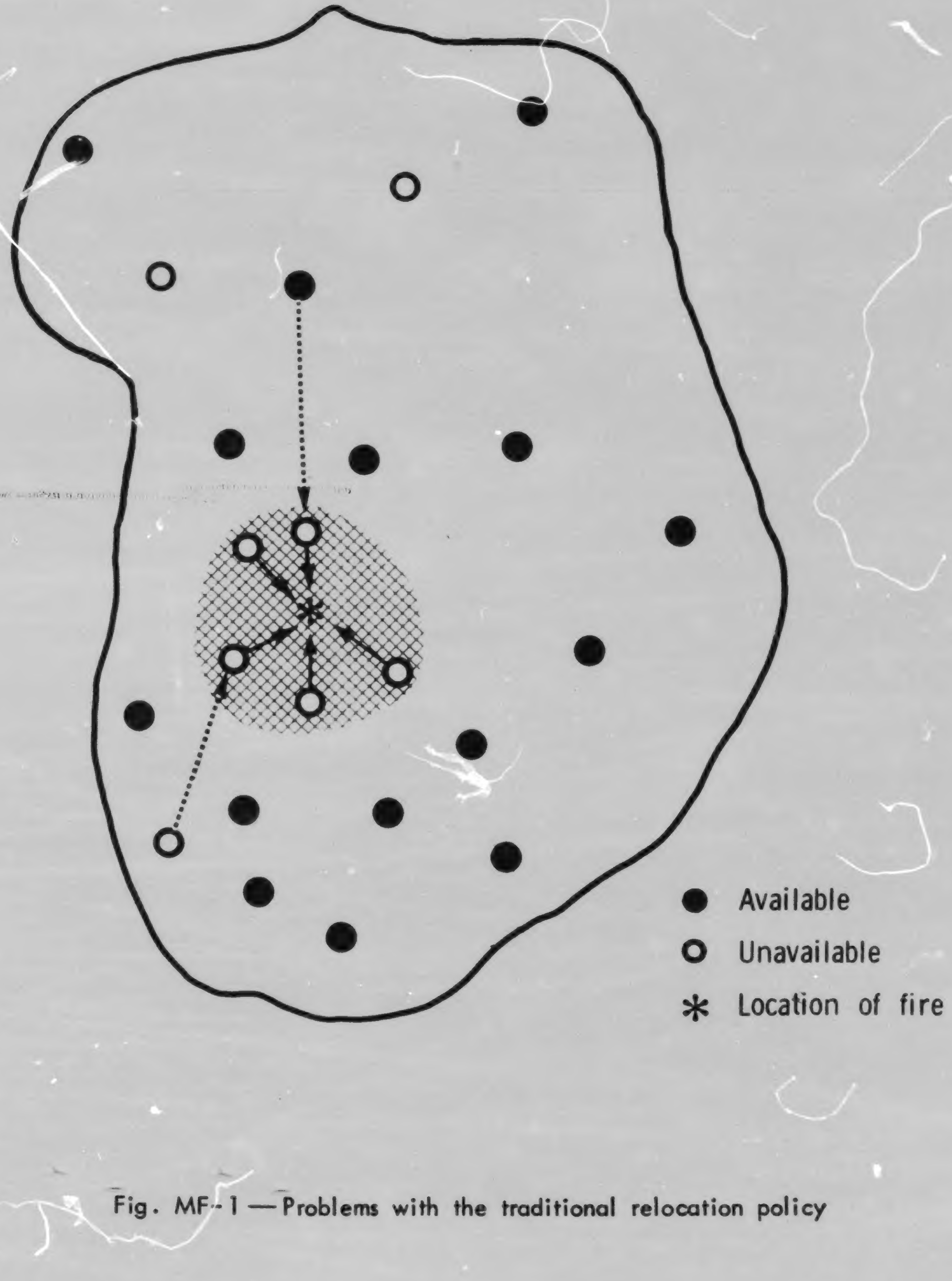
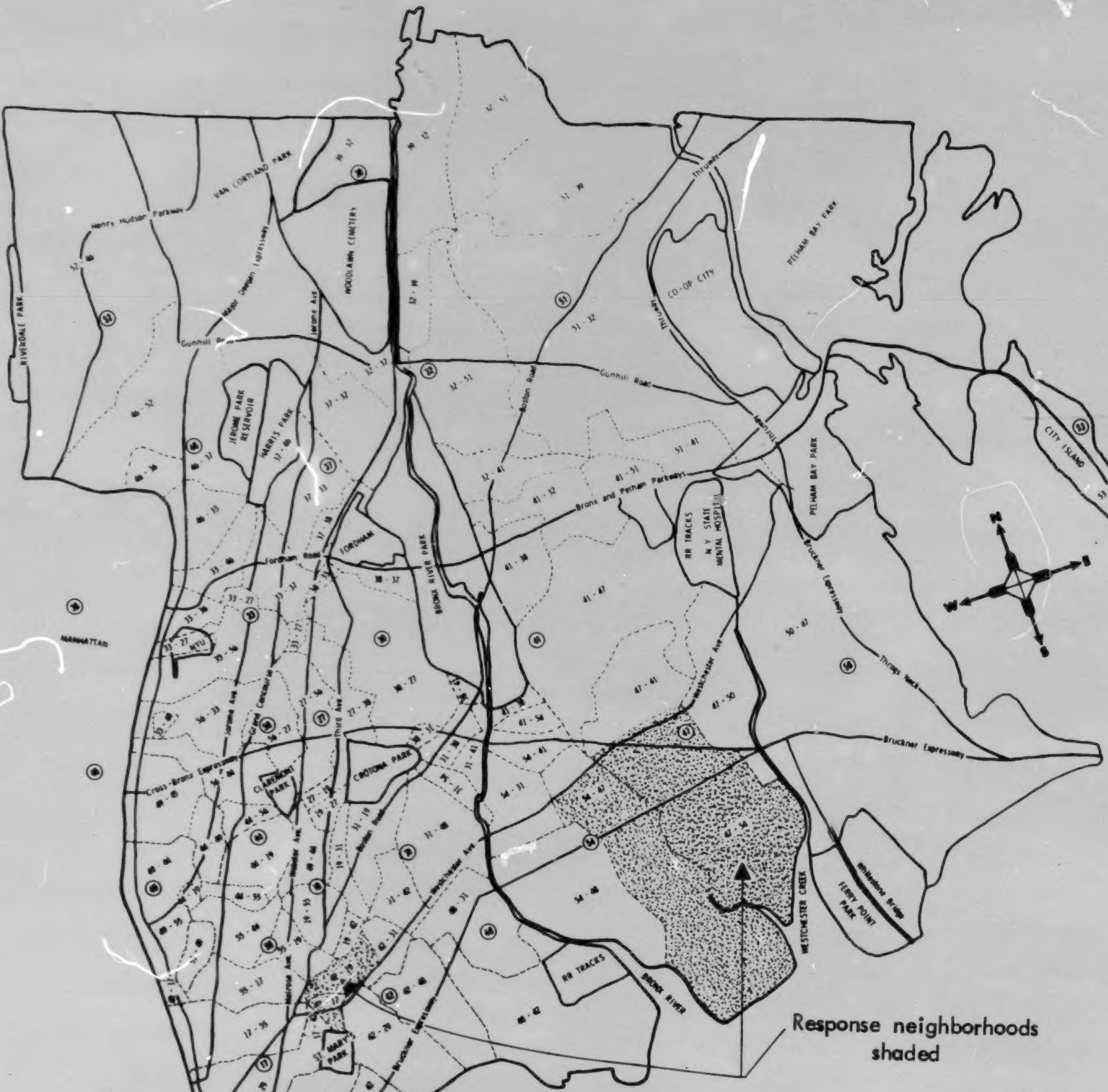

● Available
○ Unavailable
* Location of fire

Fig. MF-1 — Problems with the traditional relocation policy


Henry Hudson Parkway
VAN CORTLAND PARK
RIVERDALE PARK
WOODLAWN CEMETERY
Major Deegan Expressway
Jerome Ave
Gunhill Road
JEROME PARK RESERVOIR
HARRIS PARK
FORDHAM
Fordham Road
BRONX RIVER PARK
Boston Road
Bronx and Pelham Parkway
Thruway
CO-OP CITY
PELHAM BAY PARK
CITY ISLAND
RR TRACKS
N.Y. STATE MENTAL HOSPITAL
Bruckner Expressway
Throgs Neck
MANHATTAN
NYU
Grand Concourse
Third Ave
Cross-Bronx Expressway
CLAREMONT PARK
CROTONA PARK
Westchester Ave
Melrose Ave
Southern Blvd
ST. MARY PARK
WESTCHESTER CREEK
FERRY POINT PARK
Whitestone Bridge
BRONX RIVER
Willis Ave Bridge
Tri-Boro Bridge
N
E
S
W

Response neighborhoods shaded

Legend: 47-54 means ladder 47 is first-due and ladder 54 is second-due. A response neighborhood corresponds to two ladders, independent of their arrival order.

Fig. MF-2 — Ladder response neighborhoods in the Bronx

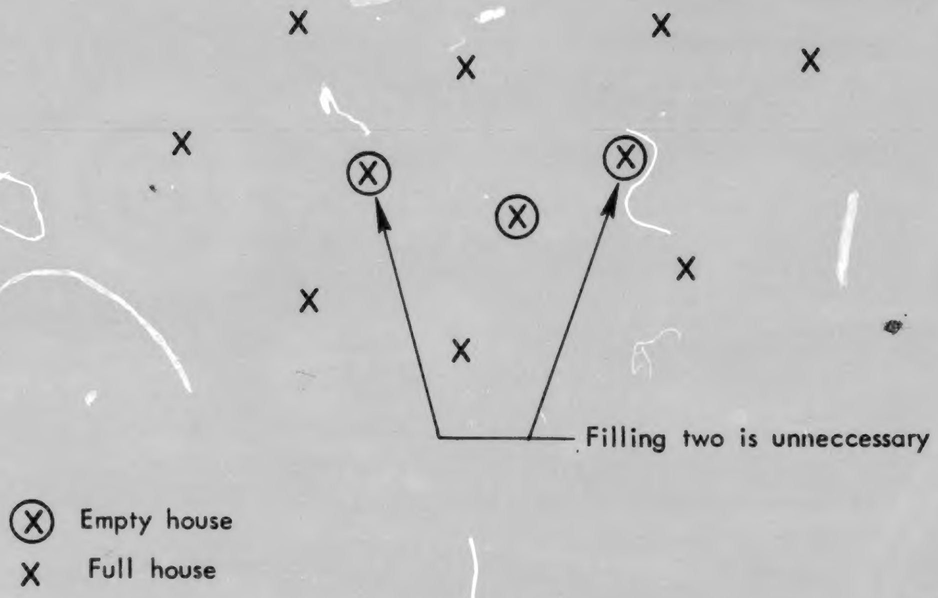

Filling two is unneccessary
⊗ Empty house
X Full house

Fig. MF-3

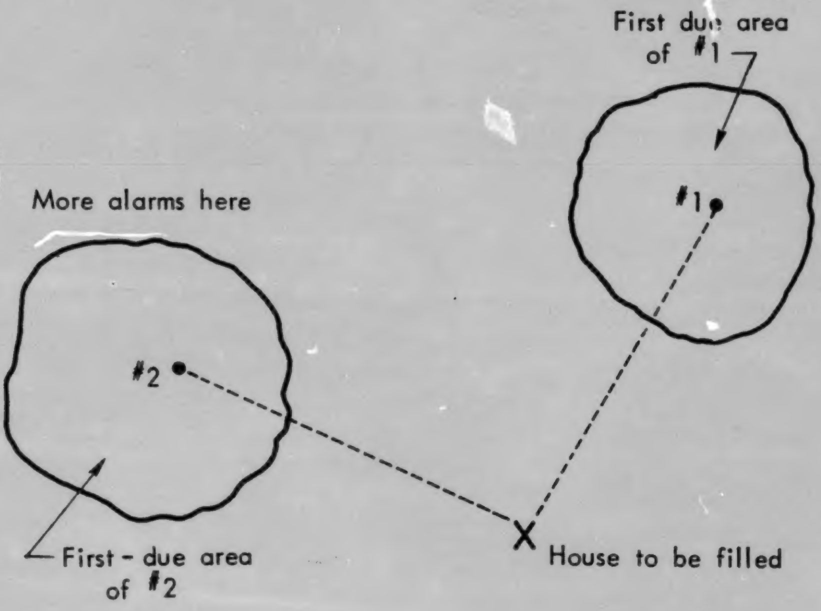

First due area of #1
More alarms here
#1
#2
First - due area of #2
House to be filled

Fig. MF-4

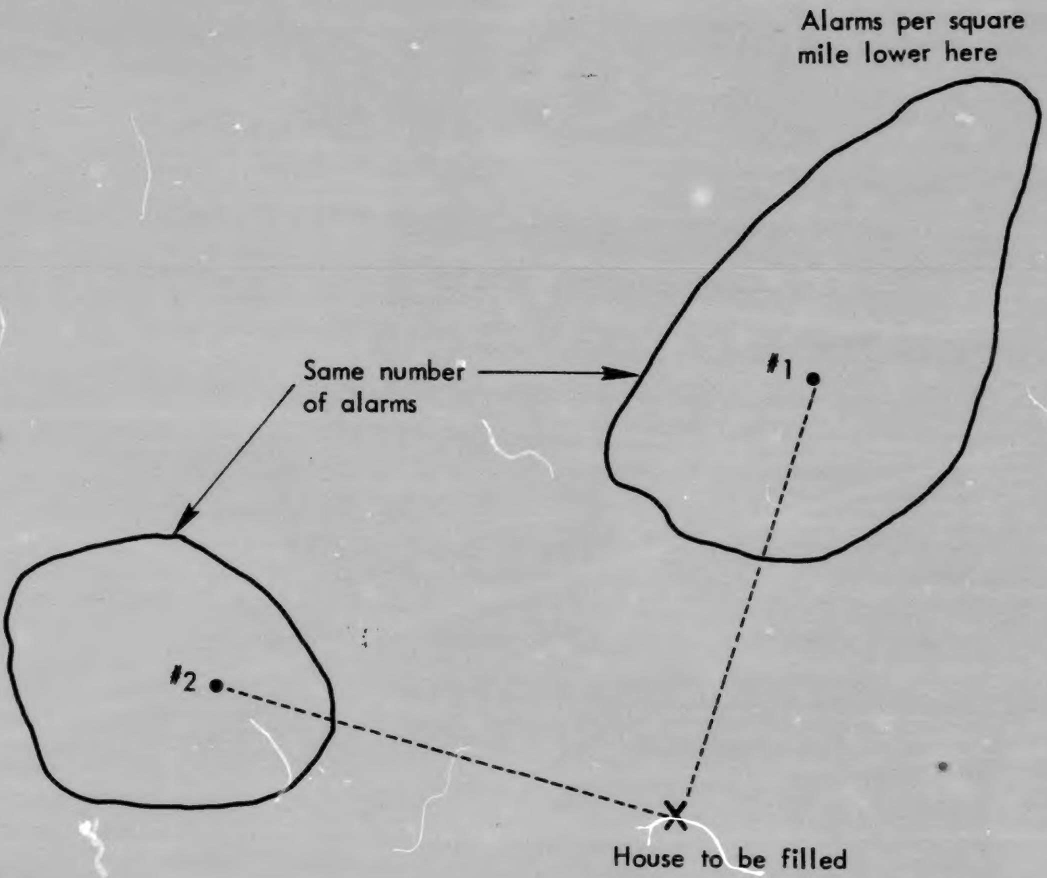

Alarms per square mile lower here
Same number of alarms
#1
#2
House to be filled

Fig. MF-5

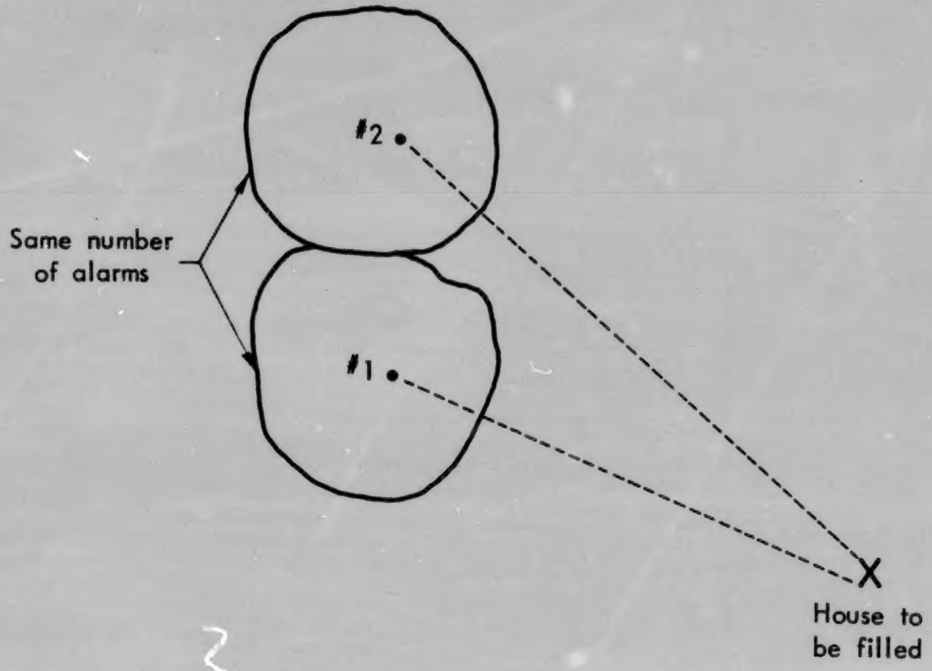
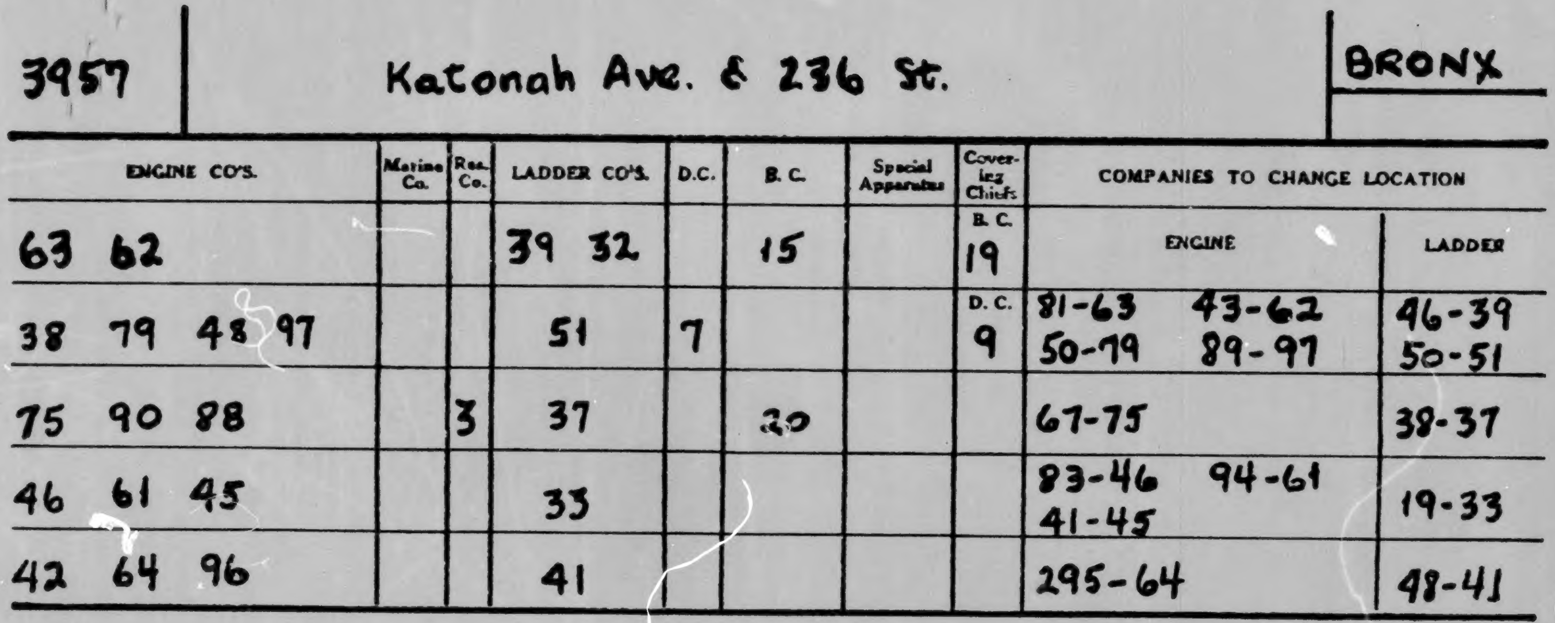

#2
#1
Same number of alarms
House to be filled

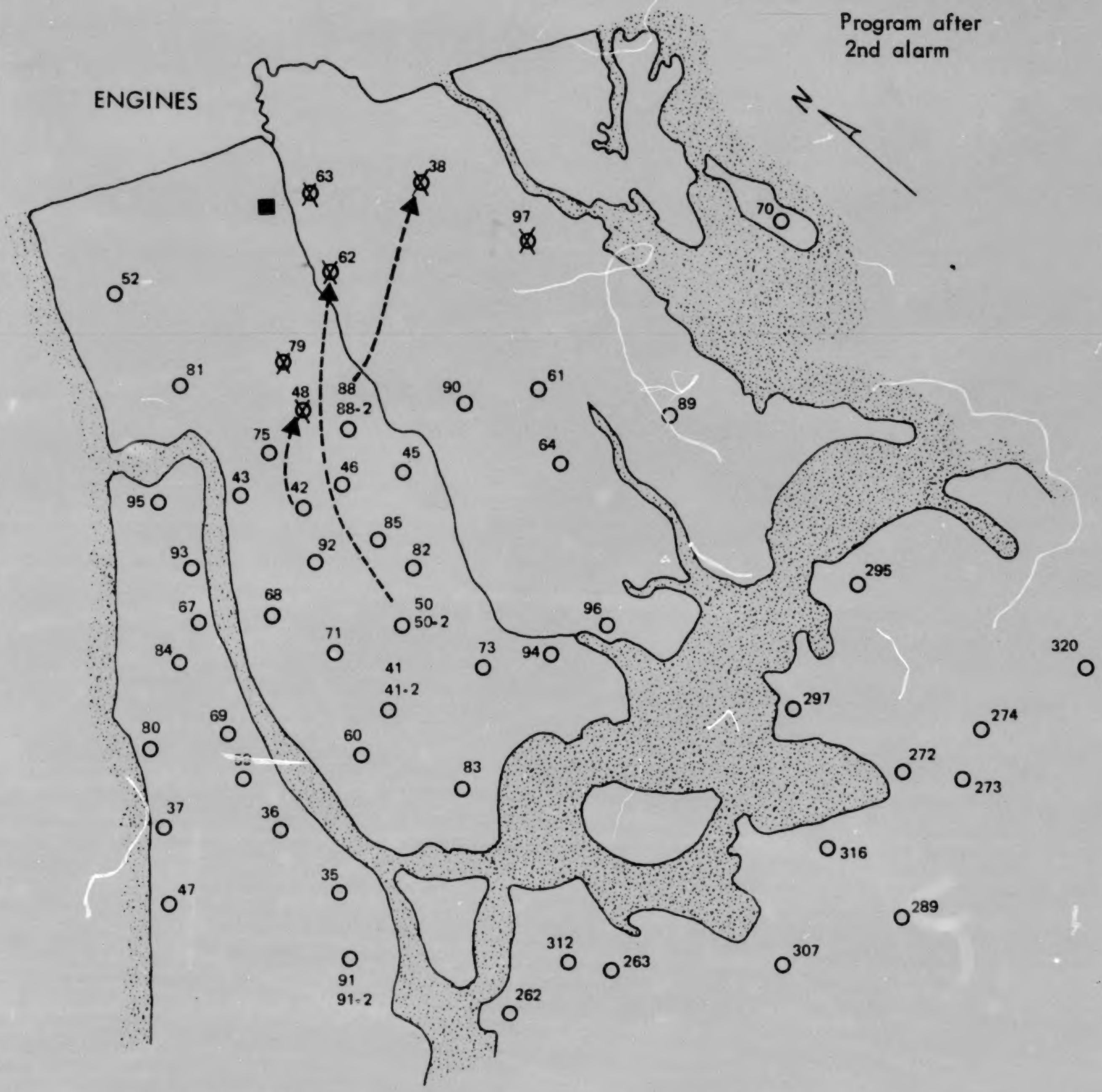
Fig. MF-6



3957 | Katonah Ave. & 236 St. | BRONX

ENGINE CO'S.	Marine Co.	Res. Co.	LADDER CO'S.	D.C.	B. C.	Special Apparatus	Covering Chiefs	COMPANIES TO CHANGE LOCATION ENGINE	COMPANIES TO CHANGE LOCATION LADDER
63 62			39 32		15		B. C. 19		
38 79 48 97			51	7			D. C. 9	81-63 43-62 50-79 89-97	46-39 50-51
75 90 88		3	37		20			67-75	38-37
46 61 45			33					83-46 94-61 41-45	19-33
42 64 96			41					295-64	48-41

Fig. MF-7—Alarm assignment card (AAC) for Bronx box 3957


Program after
2nd alarm
ENGINES
N
63
38
97
70
62
52
79
81
88
88-2
90
61
48
89
75
64
45
43
46
42
95
85
92
82
93
295
68
50
50-2
67
96
71
84
73
94
320
41
41-2
297
274
69
80
60
272
273
83
37
36
316
35
47
289
312
263
307
91
91-2
262

LEGEND :

○ Fire station with all companies available

⊗ Company has just been dispatched to a fire

⌀ One company remains in a station which usually has two companies

● Station is vacant by virtue of a previous dispatch

LEGEND :

R○ Station is occupied by a relocated unit

◉ Station is vacant by virtue of a previous relocation

⟶ Dispatch

----▶ Relocation

■ Location of a fire

Fig. MF-8

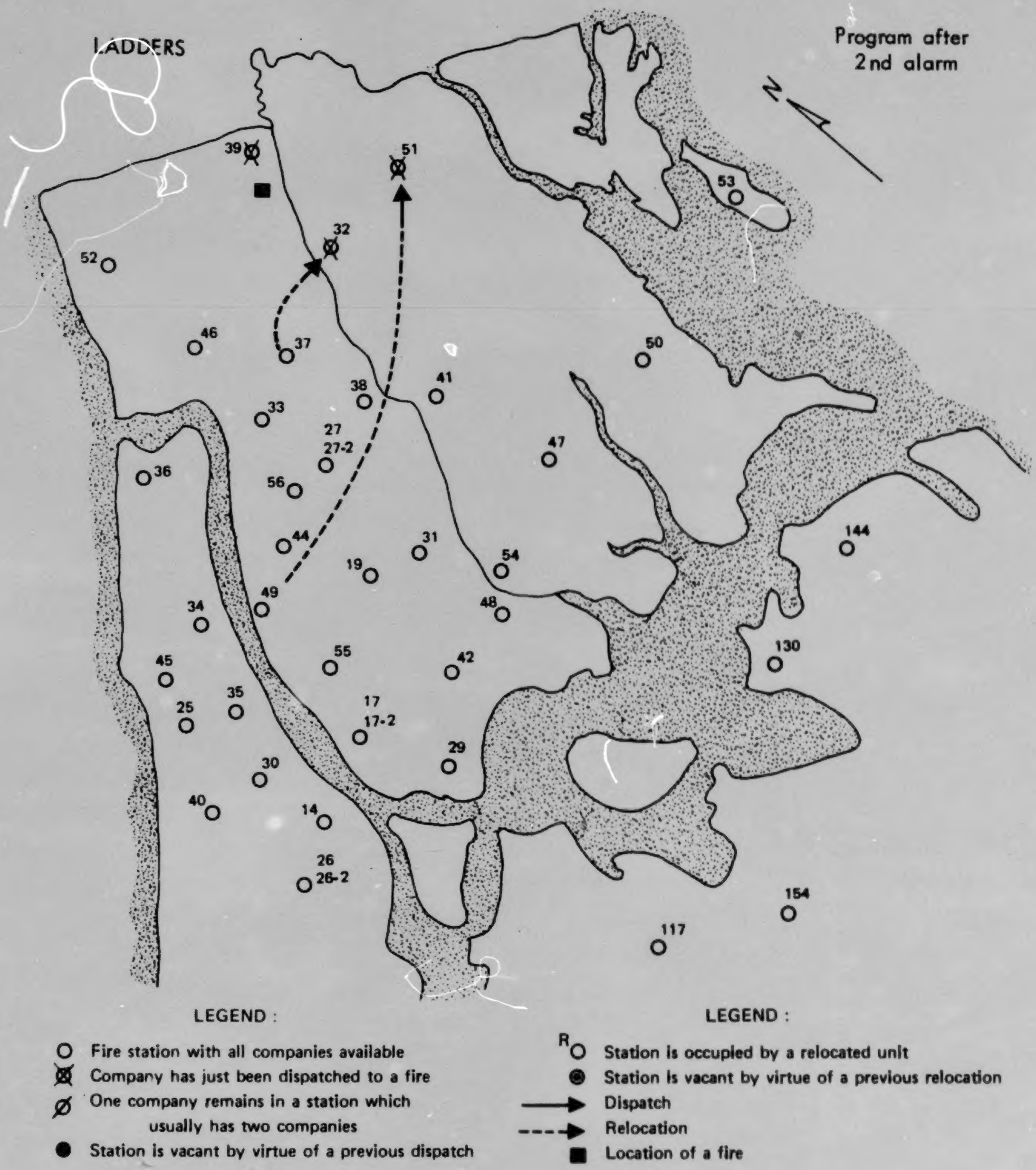

LADDERS
Program after 2nd alarm
N
39
51
53
32
52
46
37
50
38
41
33
27
27-2
47
36
56
144
44
31
19
54
49
48
34
130
55
42
45
35
25
17
17-2
29
30
40
14
26
26-2
154
117
LEGEND :
○ Fire station with all companies available
Company has just been dispatched to a fire
One company remains in a station which usually has two companies
● Station is vacant by virtue of a previous dispatch
LEGEND :
R○ Station is occupied by a relocated unit
Station is vacant by virtue of a previous relocation
Dispatch
Relocation
■ Location of a fire

Fig. MF-9

Running card after 2nd alarm

ENGINES

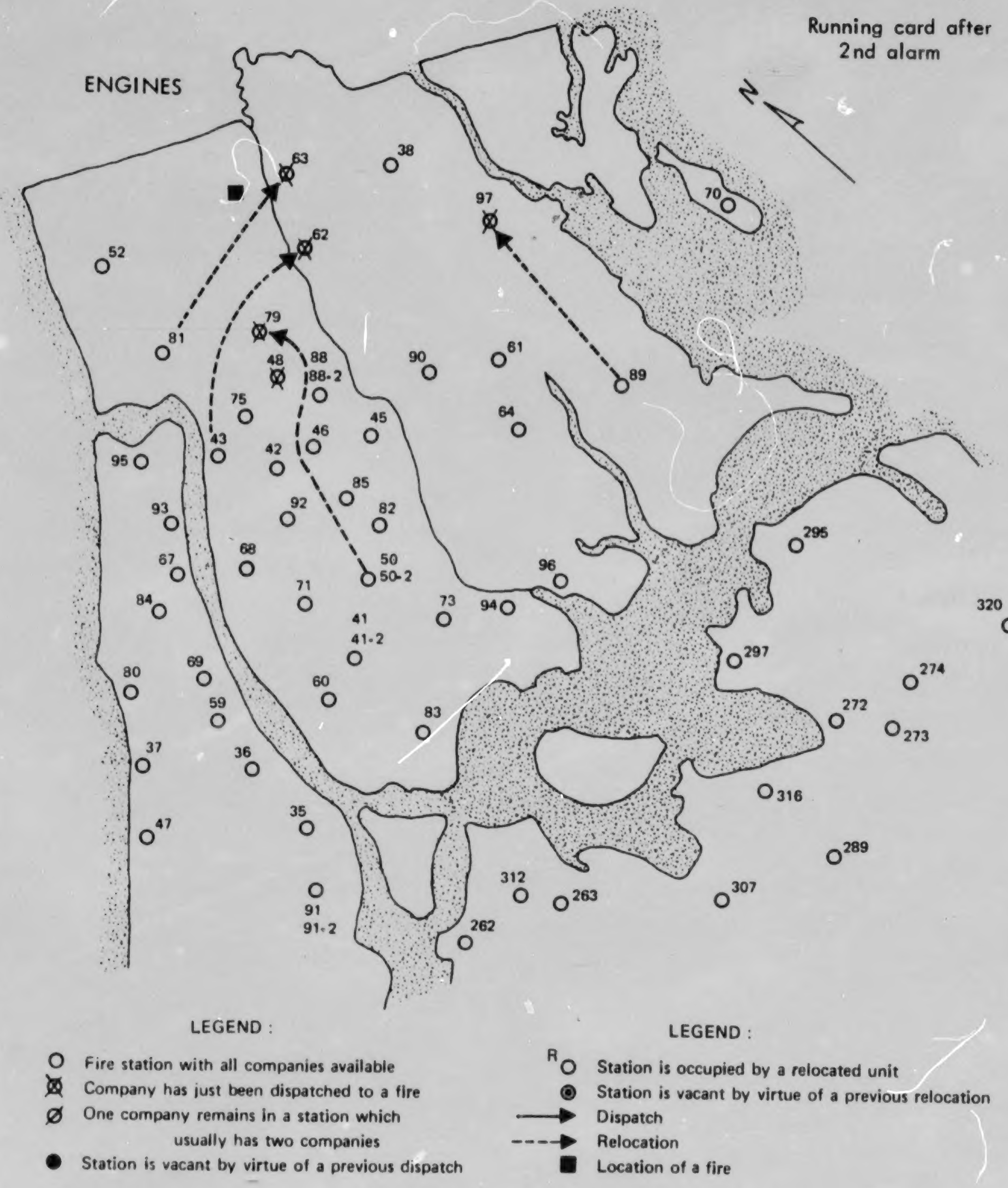
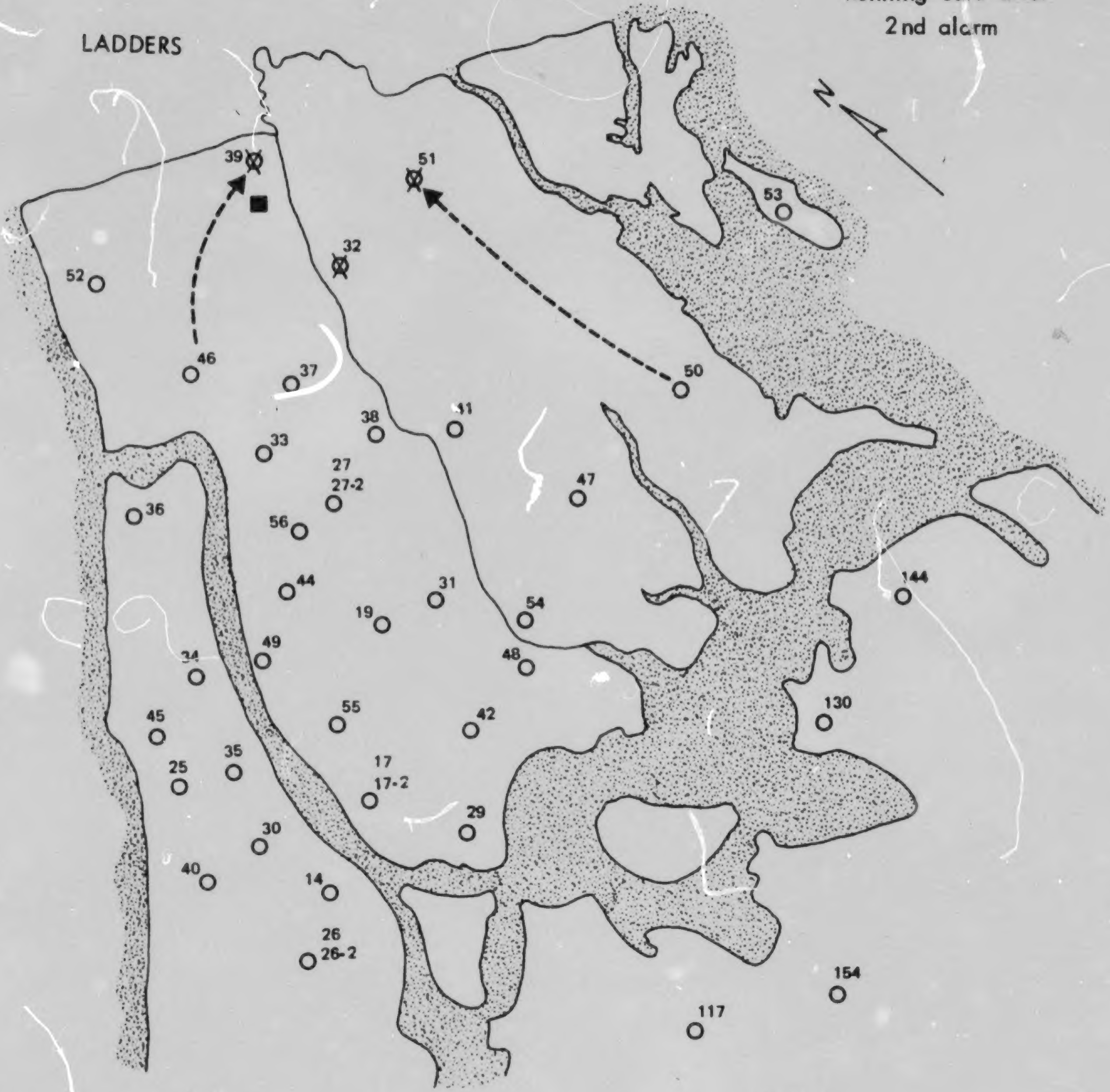

N
63
38
97
70
52
62
81
79
48
88
88-2
90
61
89
75
43
46
45
64
95
42
85
92
82
93
68
50
50-2
96
295
67
71
73
94
320
84
41
41-2
297
274
80
69
60
272
59
83
273
37
36
316
35
47
289
312
263
307
91
91-2
262
LEGEND :
○ Fire station with all companies available
⊗ Company has just been dispatched to a fire
∅ One company remains in a station which usually has two companies
● Station is vacant by virtue of a previous dispatch
LEGEND :
R○ Station is occupied by a relocated unit
◉ Station is vacant by virtue of a previous relocation
Dispatch
Relocation
■ Location of a fire

Fig. MF-10

Running card after 2nd alarm

LADDERS


N
39
51
53
32
52
46
37
50
38
41
33
27
27-2
47
36
56
44
31
144
19
54
49
34
48
45
55
42
130
25
35
17
17-2
29
30
40
14
26
26-2
154
117

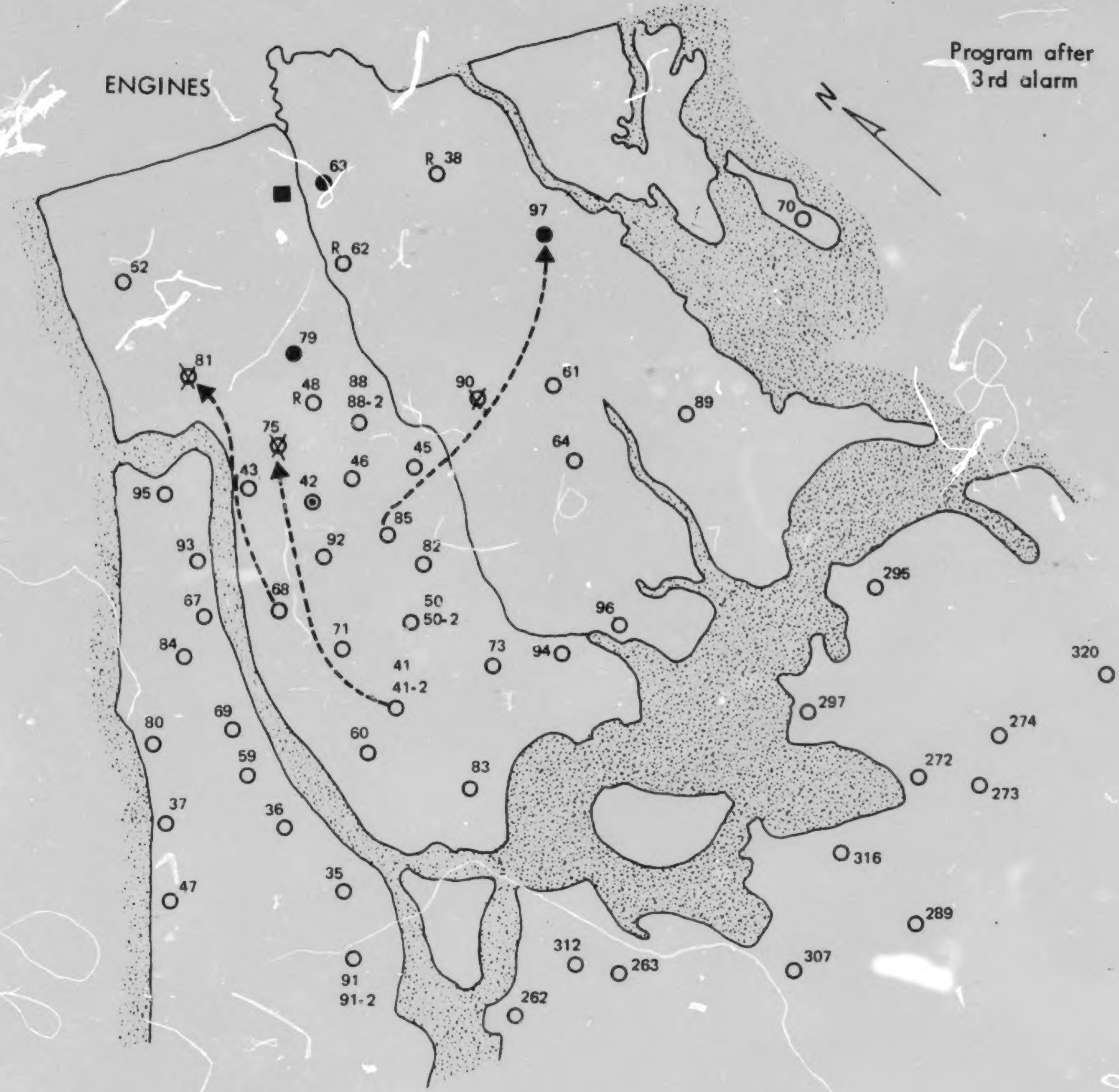
LEGEND :

○ Fire station with all companies available
⊠ Company has just been dispatched to a fire
ø One company remains in a station which usually has two companies
● Station is vacant by virtue of a previous dispatch

LEGEND :

R○ Station is occupied by a relocated unit
◉ Station is vacant by virtue of a previous relocation
⟶ Dispatch
- - -➤ Relocation
■ Location of a fire

Fig. MF-11


ENGINES
Program after 3rd alarm
N
63
R 38
97
70
R 62
52
79
81
48
R
88
88-2
90
61
89
75
43
42
46
45
64
95
85
92
82
93
68
67
50
50-2
96
71
84
73
94
320
41
41-2
297
274
80
69
60
59
272
273
83
37
36
316
35
47
289
312
263
307
91
91-2
262

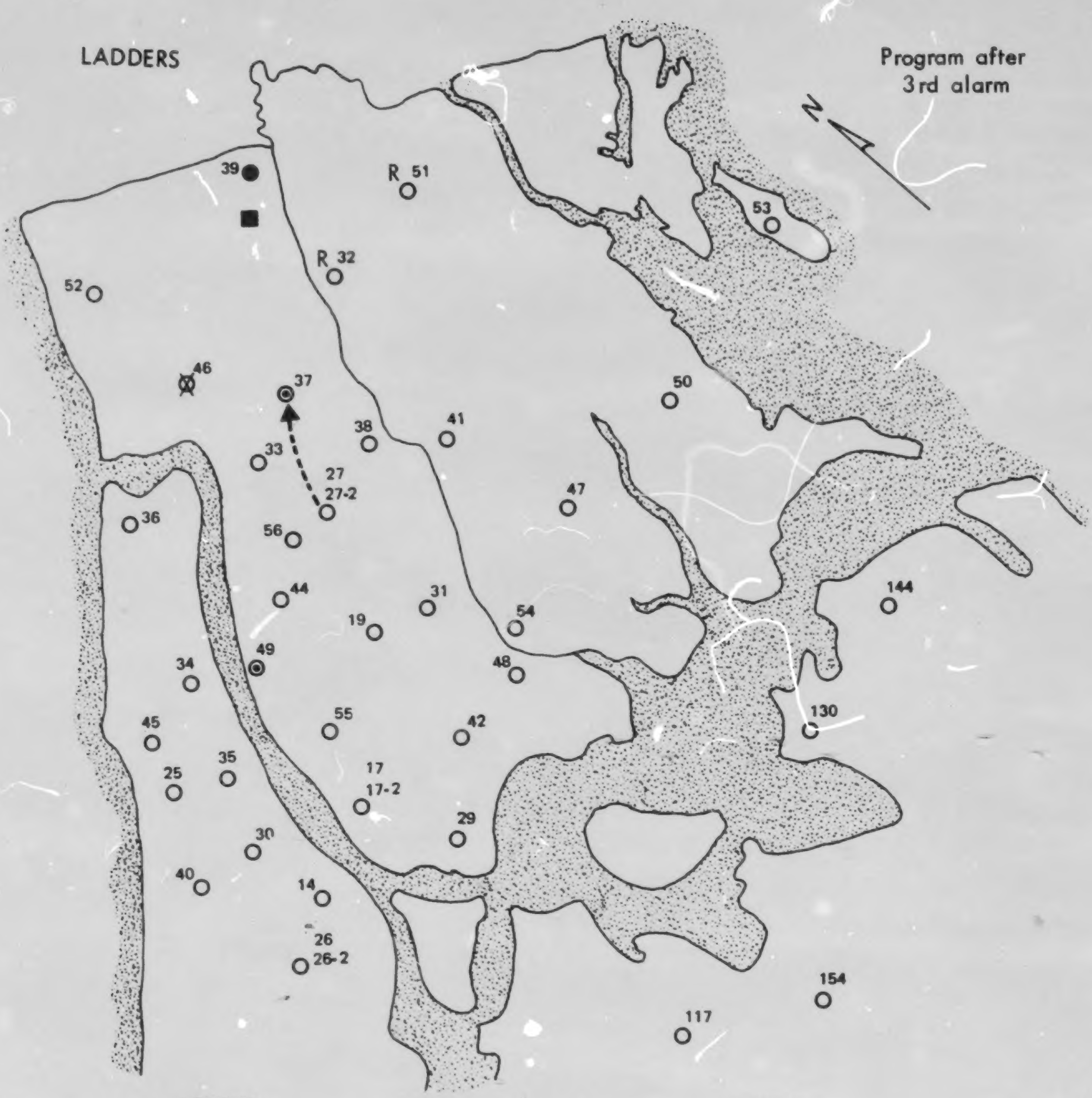
LEGEND :

○ Fire station with all companies available
⊗ Company has just been dispatched to a fire
∅ One company remains in a station which usually has two companies
● Station is vacant by virtue of a previous dispatch

LEGEND :

R○ Station is occupied by a relocated unit
◉ Station is vacant by virtue of a previous relocation
⟶ Dispatch
⇢ Relocation
■ Location of a fire

Fig. MF-12


LADDERS
Program after 3rd alarm
N
39
R 51
53
R 32
52
46
37
50
41
38
33
27
27-2
47
36
56
44
31
144
19
54
49
34
48
130
55
45
42
17
17-2
35
25
29
30
40
14
26
26-2
154
117

LEGEND :

○ Fire station with all companies available

⊠ Company has just been dispatched to a fire

ø One company remains in a station which usually has two companies

● Station is vacant by virtue of a previous dispatch

LEGEND :

R○ Station is occupied by a relocated unit

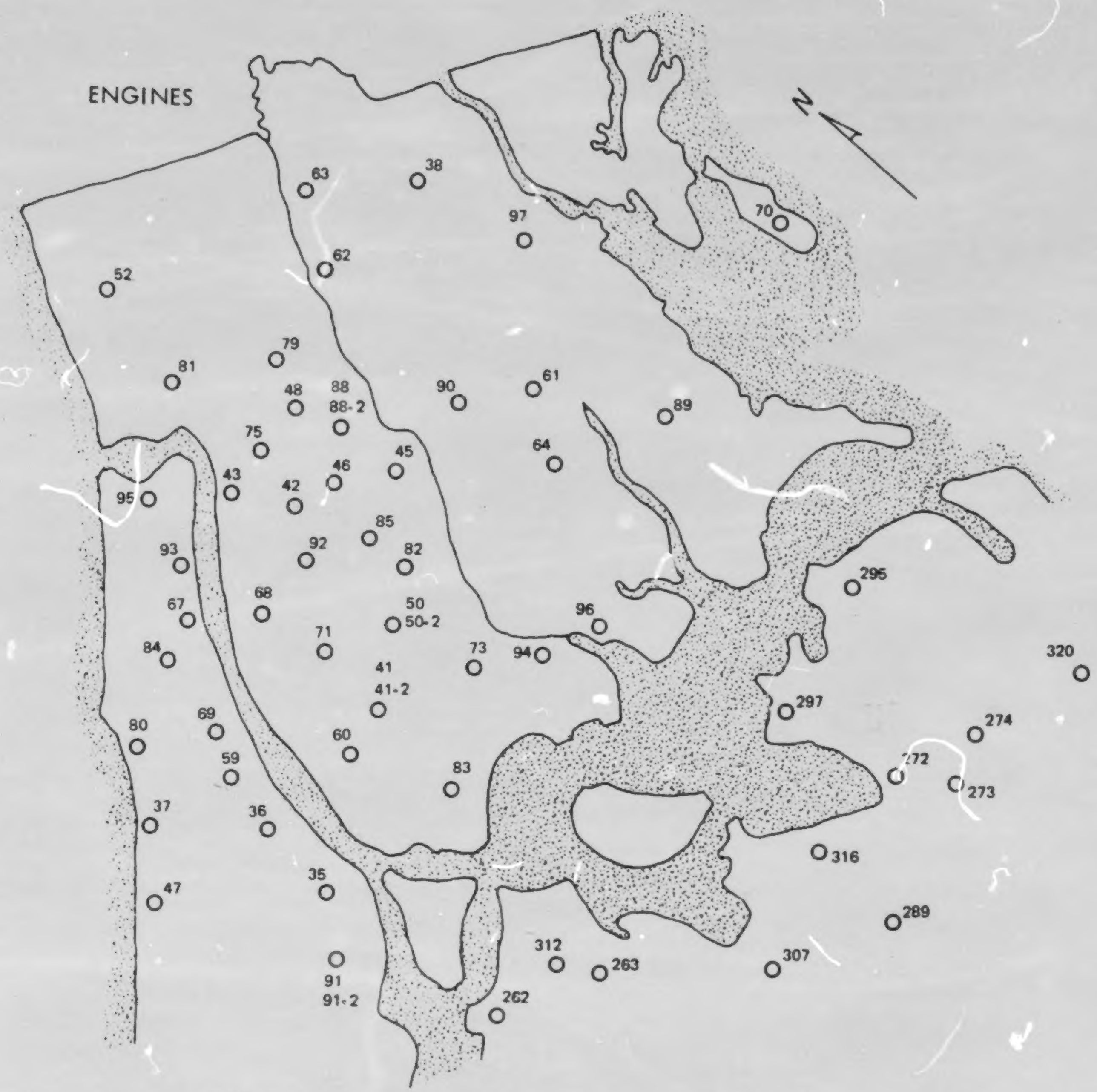
⦿ Station is vacant by virtue of a previous relocation

⟶ Dispatch

- - -→ Relocation

■ Location of a fire

Fig. MF-13


ENGINES
N
63
38
97
70
62
52
79
81
48
88
88-2
90
61
89
75
45
64
46
43
42
95
85
92
82
93
68
50
50-2
67
96
295
71
84
73
94
41
41-2
320
297
274
80
69
60
59
272
273
83
37
36
316
35
47
289
312
263
307
91
91-2
262

LEGEND :

○ Fire station with all companies available

☒ Company has just been dispatched to a fire

Ø One company remains in a station which usually has two companies

● Station is vacant by virtue of a previous dispatch

LEGEND :

R○ Station is occupied by a relocated unit

◉ Station is vacant by virtue of a previous relocation

→ Dispatch

⇢ Relocation

■ Location of a fire

Fig. MF-14

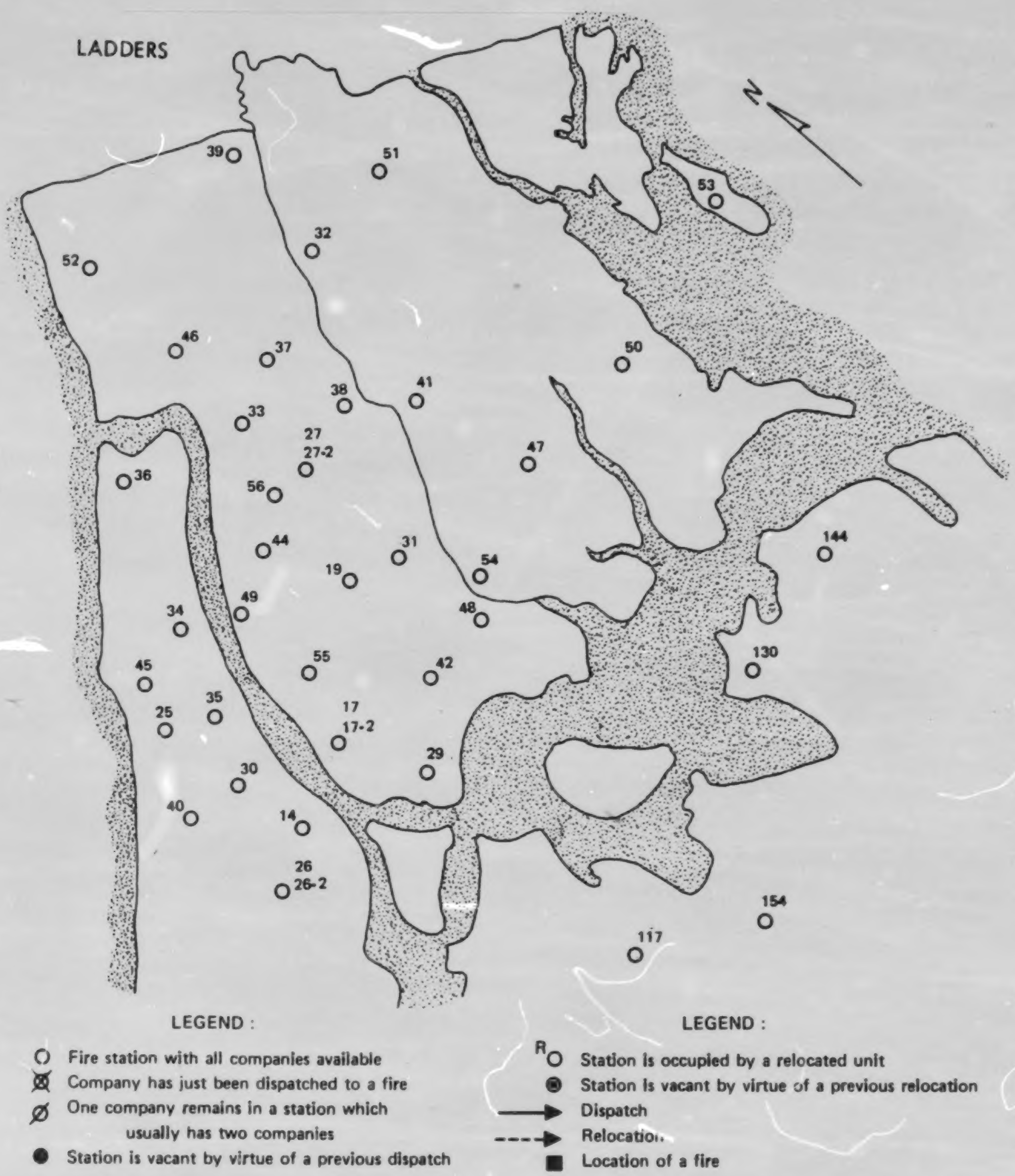

LADDERS
N
39
51
53
32
52
46
37
50
38
41
33
27
27-2
47
36
56
44
31
54
144
19
49
48
34
55
42
130
45
35
25
17
17-2
29
30
40
14
26
26-2
154
117
LEGEND :
○ Fire station with all companies available
⊠ Company has just been dispatched to a fire
Ø One company remains in a station which usually has two companies
● Station is vacant by virtue of a previous dispatch
LEGEND :
R○ Station is occupied by a relocated unit
◉ Station is vacant by virtue of a previous relocation
→ Dispatch
--→ Relocation
■ Location of a fire

Fig. MF-15

LECTURE IF

INITIAL DISPATCH
FOR FIRE SERVICE AUDIENCES

Time: Approx. 40 minutes

Objective: To show the students (a) that the history of alarms at an alarm box can provide valuable information for determining the number of units to be dispatched to a box alarm, and (b) that sometimes the closest unit may not be the best to send.

Activity	References and Notes
1. INTRODUCTION	
• How many should be sent?	
-- Different cities have different policies	
-- When alarm rate is high, city might want to reduce its normal response to conserve resources	
-- There is a way to do this rationally	
• Which ones should be sent?	
-- Always send closest when alarm rate is low	
-- If alarm rate is high, this policy is not necessarily the best	

Activity	References and Notes

2. HOW MANY?

(a) Objectives

- Try to send what is needed
- Get all units needed to the scene as rapidly as possible
- Don't have units make too many unnecessary responses

(b) How alarm is received is important

- Telephone - receive information that helps dispatcher decide
- Box - little information to go on
  - therefore, will restrict discussion to how many to send to box alarms

(c) When is there a decision?

- May want to hold back resources (not send full response) if alarm rate in region of incoming alarm is high enough so that the chance of having two alarms in progress at one time is not negligible (say 25%)

(d) The tradoff: Use send 1 ladder versus send 2 ladders as example

- Send 1 and need 2:
  - -- second ladder delayed
  - -- increased loss at fire
- Send 2 and need 1:
  - -- second ladder unavailable for another alarm (only important if there is a good probability that there will be another alarm while it is responding)
  - -- makes unnecessary response

Activity	References and Notes

2. HOW MANY? (continued)

   (e) Approach: Considers up to four factors

      (i) The probability that the incoming alarm is serious

         -- the greater the probability, the more units dispatched

         -- there are usually predictable box-to-box variations in probability serious, e.g., boxes 2277 and 2209 in Bronx

         -- this is the most important factor to consider

            - using this factor, can modify running cards--add to manual dispatching system (e.g., NYC's adaptive response)

      (ii) The expected alarm rate in the area surrounding the alarm

         -- the greater the alarm rate, the fewer units dispatched

         -- implies that dispatch policy to the same location might vary by time of day

      (iii) The number of units available in the area surrounding the alarm

         -- the more units available, the more units dispatched

         -- if you want to include this factor, probably need a computer to keep track of status

      (iv) The workload of the companies involved

         -- the higher their workload, the fewer units dispatched

   (f) Method: Use a "cost" function to blend all the factors, then (for example)

         -- send 2 if cost is less than cost to send 1

         -- send 1 if cost is lower than for send 2

Activity	References and Notes
2. HOW MANY? (continued)	

(g) Data needed if use all 4 factors in making decision

(i) For each alarm box

- Ordered list of closest engine and ladder companies
- Estimate of the probability that an incoming alarm from the box signals a serious fire (estimation procedure takes into account alarm history of box and alarm history of neighboring boxes)

(ii) For each fire-fighting company

- Expected alarm rate in its first-due area
- Number of responses made during some historical period
- Its current status (implies need for an on-line computer)

(iii) Way to calculate travel time between any house-alarm box pair

Activity	References and Notes
3. WHICH?	
• Sending closest not always best. Not sending closest can -- balance workload among companies -- provide faster response to alarms	
• Overly simplified example:	
• City with 2 companies and a send 1 dispatch policy Region A - high alarm rate Region B - low alarm rate -- Fire 1: closest company policy would dispatch Company a -- Suppose Fire 2 while Company a is busy: Company b must respond -- If send b to Fire 1 (near boundary), then a is available to respond to Fire 2. Net reduction in total response time (also, better balance in workload)	
• Note: this policy appropriate only when overall alarm rates are high	

Activity	References and Notes

4. SCENARIO

- Illustration of the circumstances under which analysis will suggest different choices for initial dispatch. The actual locations of ladder companies and alarm rates in various parts of the Bronx were used in constructing this scenario.
- At the start of the scenario, ladder companies 48, 42, and 44 have been dispatched to serious fires
- An incident is reported by box alarm at box 2267. Recommended dispatch is two ladders. Ladders 17 and 55 are dispatched
- Another incident is reported by box alarm at box 2224
- Now, because of unavailabilities in the area and a low probability of a serious fire at box 2224, the recommended dispatch is one ladder
- Ladder 17-2 is dispatched and subsequently returns to quarters after finding a false alarm at box 2224
- Now a box alarm occurs at box 2574. Although the closest ladder company is busy (as was the case at box 2224), the recommended dispatch is two ladders in this case. Box 2574 is more likely to have a serious fire than box 2224
- At this point, the unavailability of ladders are as bad as if there were a third-alarm fire somewhere between ladder 55 and ladder 19. Relocations should be made
- An incident is reported by box alarm at box 2276, which is near box 2267. If relocations have not been made, one ladder should be dispatched. If relocations have been made, two ladders should be dispatched

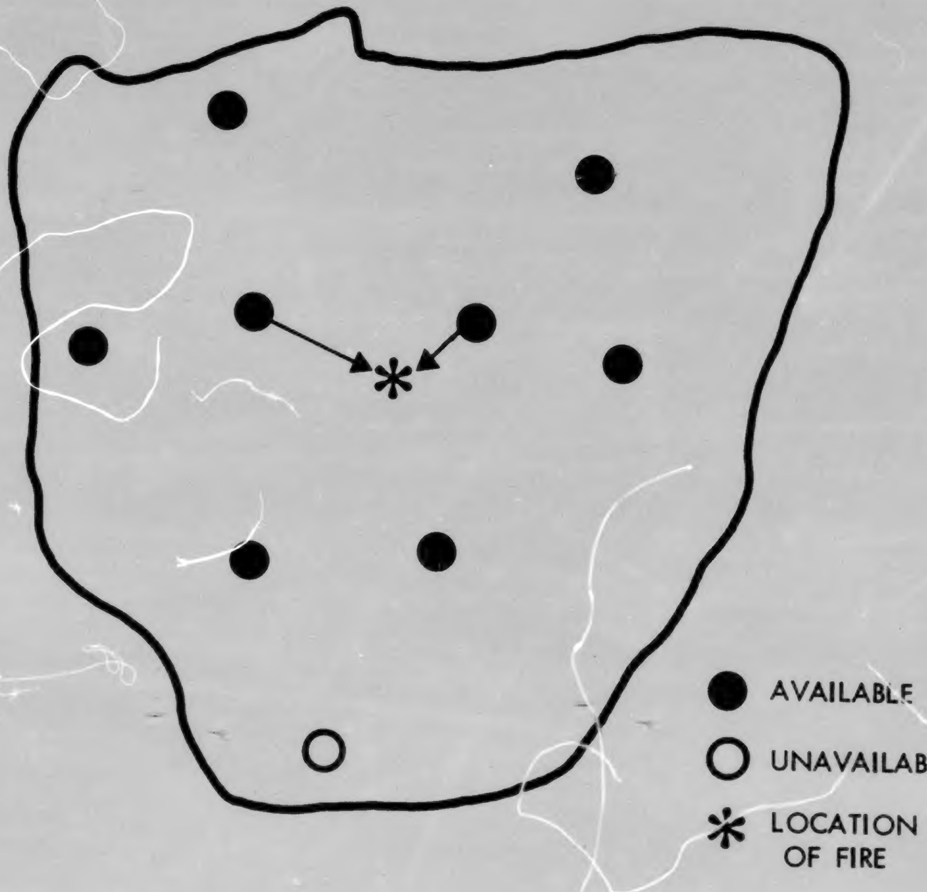

● AVAILABLE
○ UNAVAILABLE
* LOCATION OF FIRE

Fig. IF-1

Bronx box number	Predicted percent structural ('67 - '69 data)	Actual 1970 Data	
		Alarms	Structural fires
2277	0 4	96	0
2209	31.8	94	25

Fig. IF-2 — Structural fire predictions for two alarm boxes

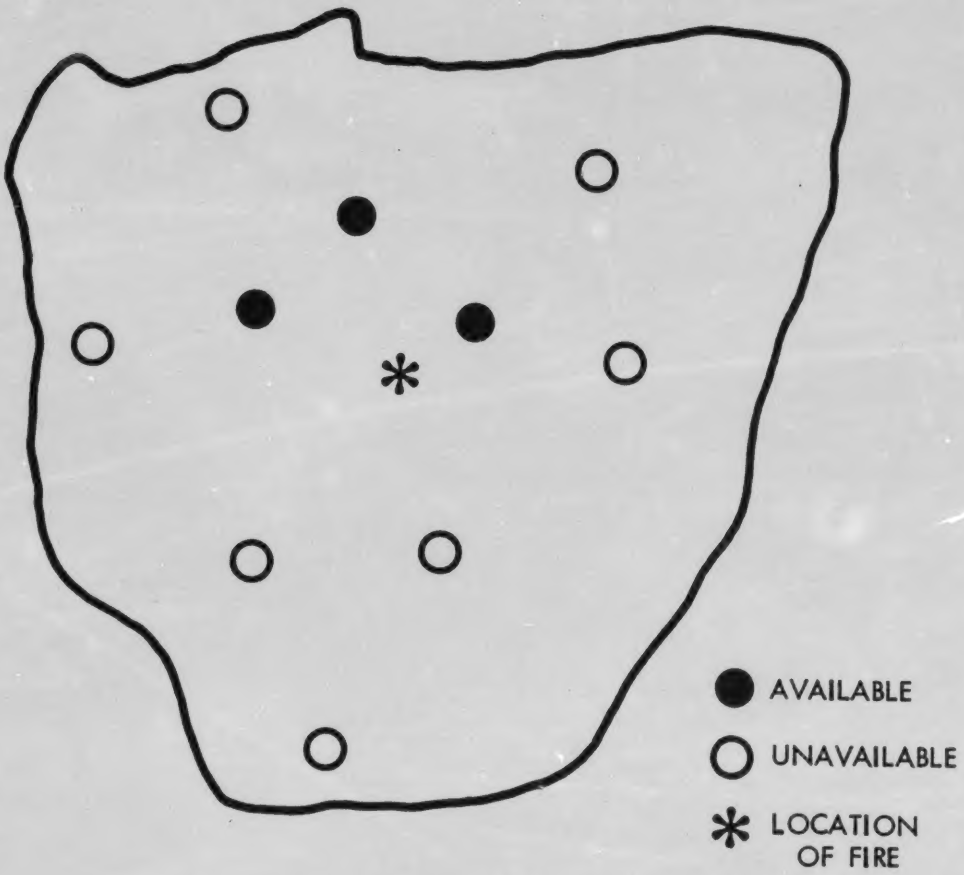

AVAILABLE
UNAVAILABLE
LOCATION OF FIRE

Fig. IF-3 — A problem with the traditional dispatching policy

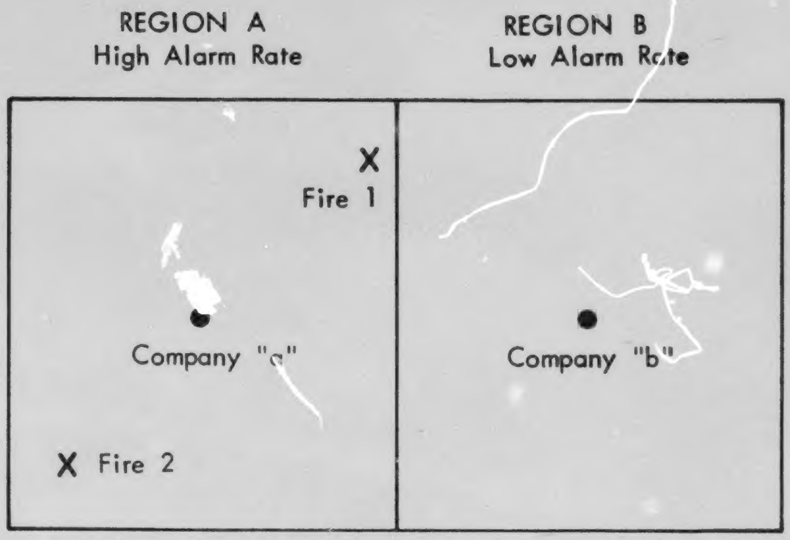

REGION A
High Alarm Rate
REGION B
Low Alarm Rate
X
Fire 1
Company "a"
X Fire 2
Company "b"

Fig. IF-4

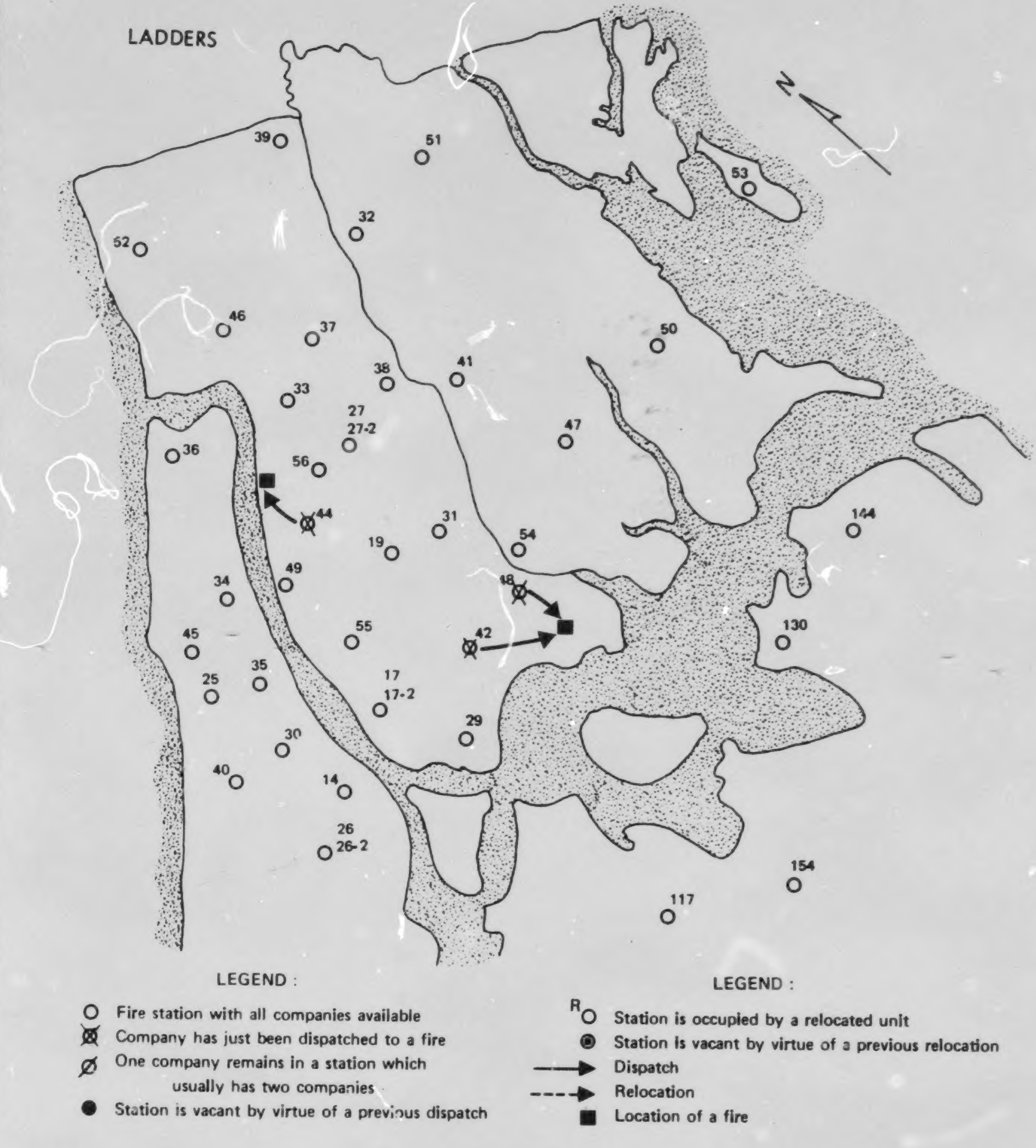

LADDERS
N
39
51
53
32
52
46
37
50
38
41
33
27
27-2
47
36
56
44
31
54
144
19
49
34
48
42
55
130
45
35
25
17
17-2
29
30
40
14
26
26-2
154
117
LEGEND :
○ Fire station with all companies available
⊗ Company has just been dispatched to a fire
∅ One company remains in a station which usually has two companies
● Station is vacant by virtue of a previous dispatch
LEGEND :
R○ Station is occupied by a relocated unit
◉ Station is vacant by virtue of a previous relocation
⟶ Dispatch
---→ Relocation
■ Location of a fire

Fig. IF-5 — Status of Bronx ladder companies at the start of the scenario

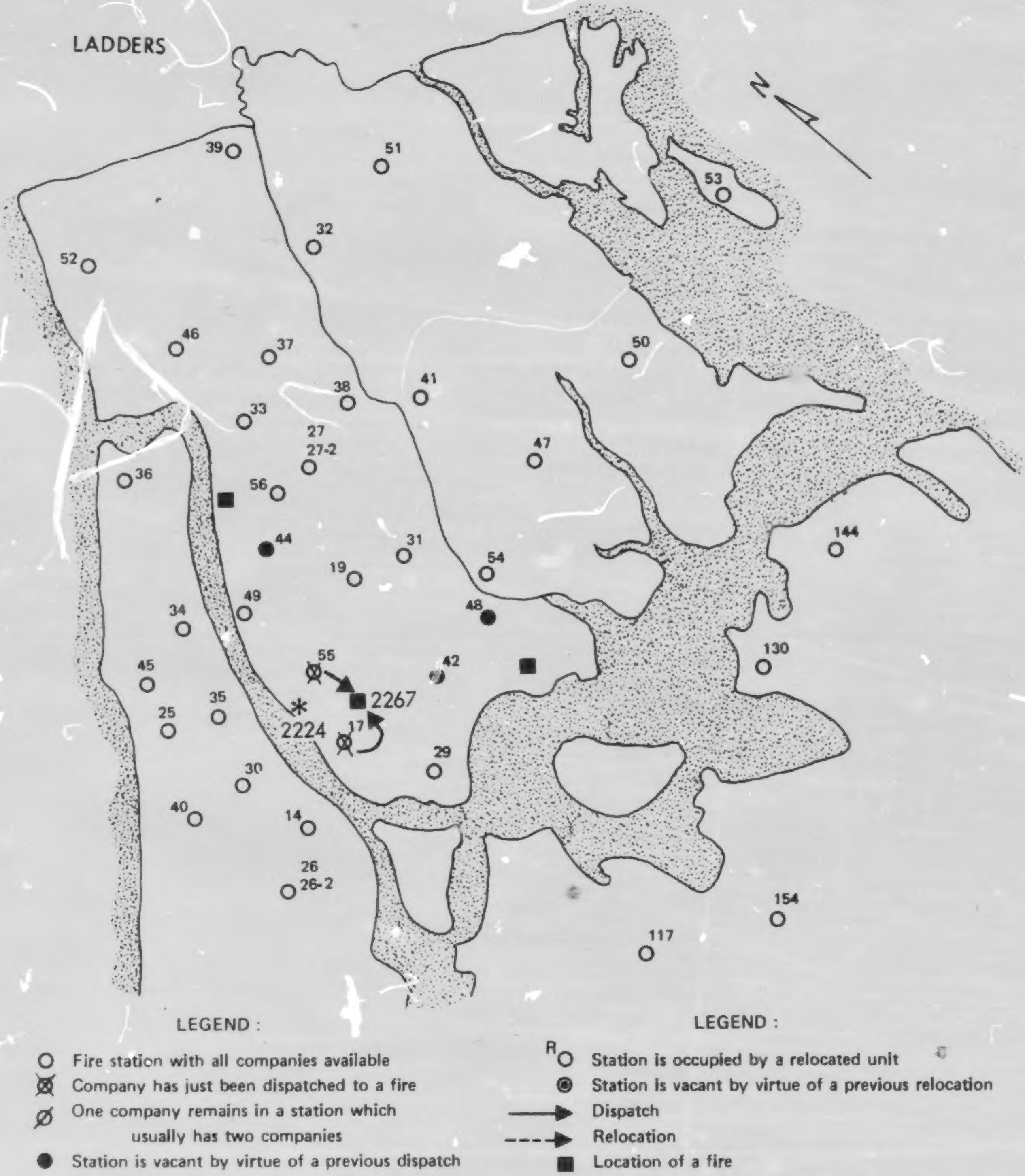

LADDERS
N
39
51
53
32
52
46
37
50
38
41
33
27
27-2
47
36
56
44
31
144
19
54
49
34
48
55
42
130
45
2267
35
2224
17
25
29
30
40
14
26
26-2
154
117
LEGEND :
○ Fire station with all companies available
⊗ Company has just been dispatched to a fire
ø One company remains in a station which usually has two companies
● Station is vacant by virtue of a previous dispatch
LEGEND :
R○ Station is occupied by a relocated unit
◉ Station is vacant by virtue of a previous relocation
→ Dispatch
- - -→ Relocation
■ Location of a fire

Fig. IF-6 — Status of Bronx ladder companies after Box 2267 is dispatched

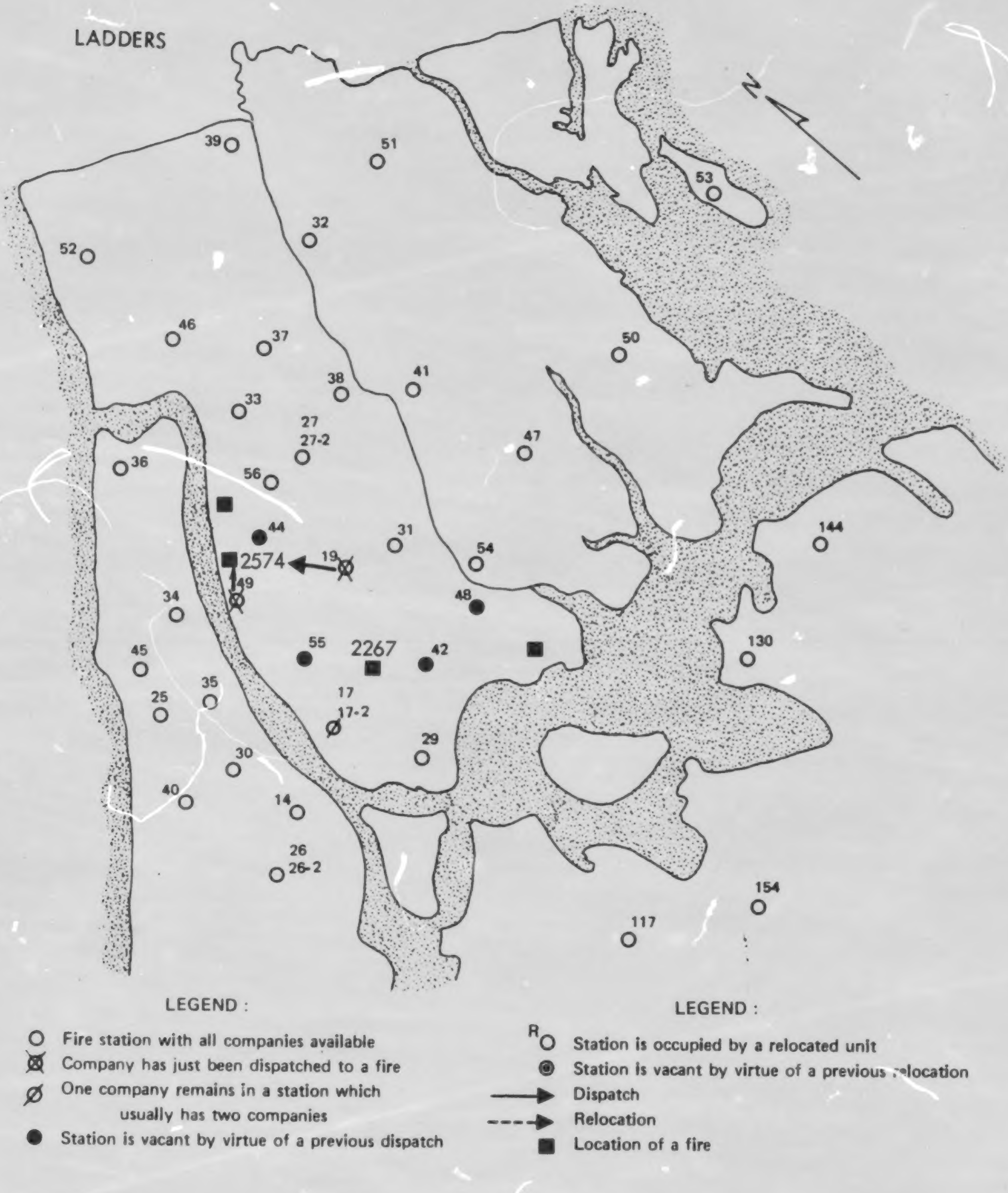

LADDERS
N
39
51
53
52
32
46
37
50
38
41
33
27
27-2
47
36
56
44
31
144
2574
19
54
149
48
34
55
2267
42
130
45
35
25
17
17-2
29
30
40
14
26
26-2
154
117
LEGEND :
○ Fire station with all companies available
⊗ Company has just been dispatched to a fire
⌀ One company remains in a station which usually has two companies
● Station is vacant by virtue of a previous dispatch
LEGEND :
R○ Station is occupied by a relocated unit
◉ Station is vacant by virtue of a previous relocation
→ Dispatch
⇢ Relocation
■ Location of a fire

Fig. IF-7 — Status of Bronx ladder companies after Box 2574 is dispatched

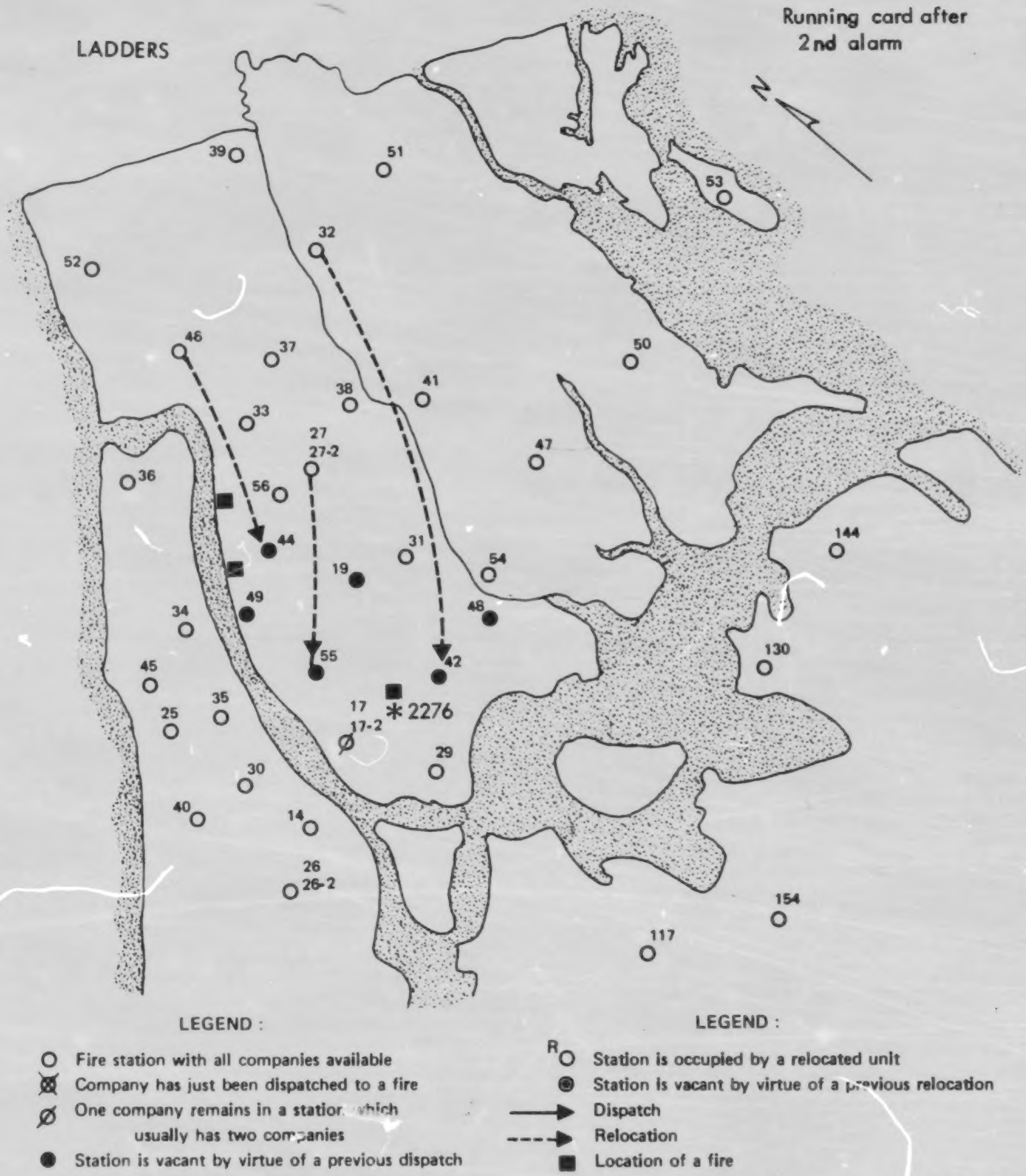

LADDERS
Running card after
2nd alarm
N
39
51
53
52
32
46
37
50
38
41
33
27
27-2
47
36
56
44
31
144
19
54
49
48
34
55
42
130
45
17
17-2
*2276
35
25
29
30
40
14
26
26-2
154
117
LEGEND:
Fire station with all companies available
Company has just been dispatched to a fire
One company remains in a station which usually has two companies
Station is vacant by virtue of a previous dispatch
LEGEND:
Station is occupied by a relocated unit
Station is vacant by virtue of a previous relocation
Dispatch
Relocation
Location of a fire

Fig. IF-8 — Status of Bronx ladder companies at time of relocation

LECTURE AP

ALLOCATION OF POLICE PATROL

Time: Approx. 40 minutes

Objective: To provide an approach to answering the question of how many patrol cars to assign to each command by hour or tour.

Activity	References and Notes
1. INTRODUCTION	
• Topic is how many patrol cars to assign to each command by hour or tour	
-- "Command" is a general term for an administratively separate geographical area of the city. Variously called precinct, division, district, unit, or area	
-- A single patrol beat or sector is not a "command." A command can be characterized by the fact that if all its patrol cars were busy, a low-priority call for service would be queued	
2. PRIORITY STRUCTURE	
• Find out what types of calls are actually handled by dispatchers as high priority (every effort will be made to locate a car to send immediately, even a supervisor or out-of-command car), medium priority (if in queue, will be dispatched as fast as possible), and low priority (can wait for dispatch)	
• It doesn't help to think about which calls should fall in each priority level, unless the intention is to change the practices of dispatchers	

Activity	References and Notes

3. ESTIMATING CALL-FOR-SERVICE WORKLOAD

- Need to know how many car-hours will be required to serve calls for service in each priority class in each hour of the day ("workload")

- This can be done by estimating the number of calls in each class and the service times separately, and multiplying these together. Or estimate workload directly from workload data

- Possible estimation methods

  -- commercially available computer programs (e.g., LEMRAS)

  -- average over past few weeks, adjust for seasonal trends

  -- graph and extrapolate

- Estimates don't have to be super-accurate to be useful. Don't get wound up in trying to improve accuracy of predictions

- Collect data from dispatcher's position

- Commands found to have unusually long service times may have a management problem. Don't just allocate more cars to them

Activity

References and Notes

4. ESTIMATE "EXTRA" UNAVAILABILITIES

- f = average fraction of a car's tour that the car is unavailable for dispatch for reasons other than dispatch to a previous call
    - -- includes meals, maintenance, patrol-initiated activities, arrest processing, etc.
    - -- include time in court if this is only part of a tour
- f may vary by command. In a given command, f may vary with call-for-service workload
- Collect data at dispatcher's position
- Draw graphs, calculate averages

5. SET LIMIT ON QUEUING

- Fraction of all calls queued
- Average waiting time in queue for
    - -- middle priority
    - -- low priority
- Overall average waiting time

Activity	References and Notes

6. NUMBER OF CARS NEEDED TO PREVENT QUEUING FROM EXCEEDING LIMIT

- Consider a particular command and a particular hour of the day
- N = number of cars to be fielded (we will try different values of N until we find the right one)
- (1-f)N = effective number of cars fielded
- (1-f)N must at least equal the estimated call-for-service workload in car-hours
- Start with N = next integer bigger than (workload)/(1-f)
- See if queuing is below specified limits with (1-f)N cars
    - -- need graphs, tables, formulas, or a computer program
- If not, increase N by one car and try again
- Keep going. The first N that works tells how many cars are needed for queuing purposes

7. EXAMPLE

How many cars are needed to assure that less than 10% of calls are delayed in a command having 3.9 car-hours of work per hour and 30% of each car's time spent unavailable for reasons other than calls for service?

Activity	References and Notes

8. CRITERIA OTHER THAN QUEUING

- See if the value of N chosen above is big enough so that (1-f)N effective cars give reasonable values for
    - -- average travel time
    - -- average patrol frequency
    - -- patrol per outside crime
    - -- (whatever you care about)
- If not, increase N until these other criteria are met

9. COMPARE WITH THE SIZE OF THE PATROL FORCE

- Add the values of N (found above) across commands, or across hours of the day, or both
- Do you have enough men to field that many car-hours?
    - -- If no, some constraints must be relaxed, or some categories of calls must be screened out (no unit will respond), or the "extra" unavailabilities must be reduced by administrative change
    - -- If yes, the extra cars can be allocated to commands or tours so as to minimize citywide average queuing delay. Or the extra cars can be assigned to special activities

Activity	References and Notes
10. COMPUTER PROGRAM	

- Computer program is available to perform these calculations

- Descriptive mode. User decides how many patrol cars are to be on duty in each command during each tour. Program displays

  - -- Percent of time cars are busy on call-for-service work
  - -- Preventive patrol frequency
  - -- Average travel time
  - -- Percent of calls queued
  - -- Average waiting time in queue, by priority level
  - -- Average total response time

- Prescriptive mode

  (a) User sets limit on any of the measures listed above. Program calculates minimum number of cars needed

  (b) User specifies total car-hours that can be fielded. Program allocates them to tours or commands or both so as to minimize

    - -- average percentage of calls placed in queue
    - -- *or*, average waiting time for some priority level
    - -- *or*, average response time

Activity	References and Notes

11. DATA NEEDED FOR PROGRAM

- Hours of the day at which tours begin. One tour can be an overlay
- Call rates and service times by hour
- Response and patrol speeds of cars
- Number of outside crimes
- Unavailability parameters

12. TYPES OF POLICY ISSUES THAT CAN BE ADDRESSED

- Number of patrol officers needed to meet standards of performance
- Which calls to "screen out" to improve performance levels with fixed resources
- Allocation by time of day within each command
- Possible benefits of an overlay tour
- Where to assign new recruits
- Deployment of a mobile patrol team (moves to different parts of the city from week to week)

13. ADVANTAGES

- Easy to use, once data are collected
- Inexpensive to run on the computer

14. DRAWBACKS

- Calculations are approximate
- User must estimate call rates and service times for the future
- No information about variations within a command

f = .30

1-f = .7

Workload = 3.9

Workload/(1-f) = 5.57

Next integer	Effective number of cars	Percent of calls delayed*
6	4.2	86
7	4.9	56
8	5.6	36
9	6.3	22
10	7.0	12.1
11	7.7	7.3
Stop.		

*From tables, graphs, or computer program.

Fig. AP-1 — Example of allocation calculation

LECTURE BP

BEAT DESIGN
FOR POLICE SERVICE AUDIENCES

This is an optional added topic for Lecture AP

Time: Approx. 15 minutes

Objective: To describe an approach to designing police patrol beats or sectors

Activity	References and Notes

1. INTRODUCTION

- Topic is how to design patrol beats or patrol sectors: the areas covered by a single patrol car
- The number of patrol beats in a command is determined from the allocation analysis
- Therefore, beats may change by time of day

2. RULES OF THUMB

- Shape of sector doesn't matter much, as long as it's compact
- If travel speeds differ in two directions, the long dimension of the sector should be in the direction of the higher speeds
- If beats don't overlap, the fraction of dispatches that are interdistrict (across beat boundaries) is at least as high as the fraction of time the average unit is unavailable
- Unit's workload is not equal to the workload generated in its beat
- Burden of central location
    - Shaded parts of the command have many calls for service
    - Number of calls for service is not high in the center
    - Car in the center is very busy because it is the dispatcher's second choice for all the busy beats

Activity	References and Notes

3. HYPERCUBE MODEL

- Permits calculation of performance characteristics for trial beat designs. You have to work out the trial designs; program doesn't help

- Required data

  -- Divide city into small areas (smaller than a beat)

  -- Call-for-service data for the small areas

  -- Some way to estimate travel times between small areas
    .. coordinates of centers
    .. experimental trips
    .. estimates of local officers
    .. computerized road network

- Performance measures calculated for each beat design

  -- Regionwide average travel time

  -- Regionwide workload imbalance

  -- Fraction of dispatches that are inter-district

  -- Workload of each patrol car

  -- Average travel time to particular locations

  -- Average travel time in each beat

  -- Average travel time of each patrol car

  -- Fraction of responses in each beat handled by the beat's assigned car

  -- Fraction of each car's responses that take it out of its beat

4. EXAMPLE OF APPLICATION

- First map and table show original design of beats (called sectors)

- Second set shows final design

Activity	References and Notes
5. ADVANTAGES	
• Easy to use, after data have been collected	
• Can handle overlapping beats, sergeant's cars, fairly complicated dispatching policies	
• Inexpensive to run on a computer	
6. DISADVANTAGES	
• Assumes one car dispatched to each incident	
• Not well suited to handle priorities	

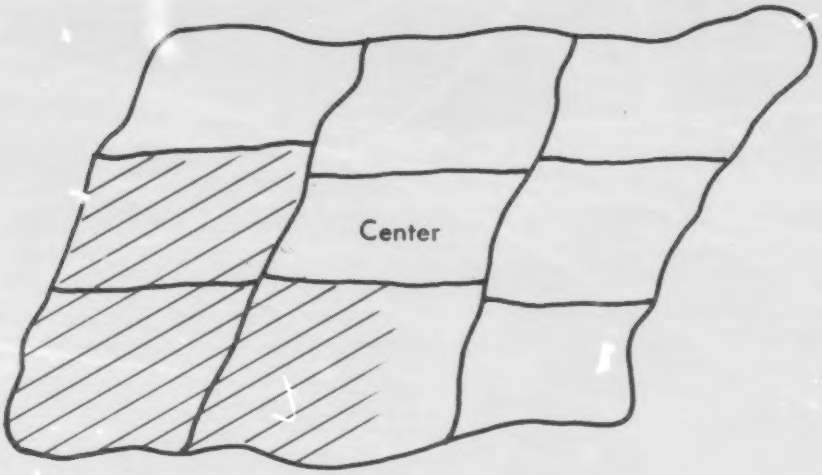


Fig. BP-1

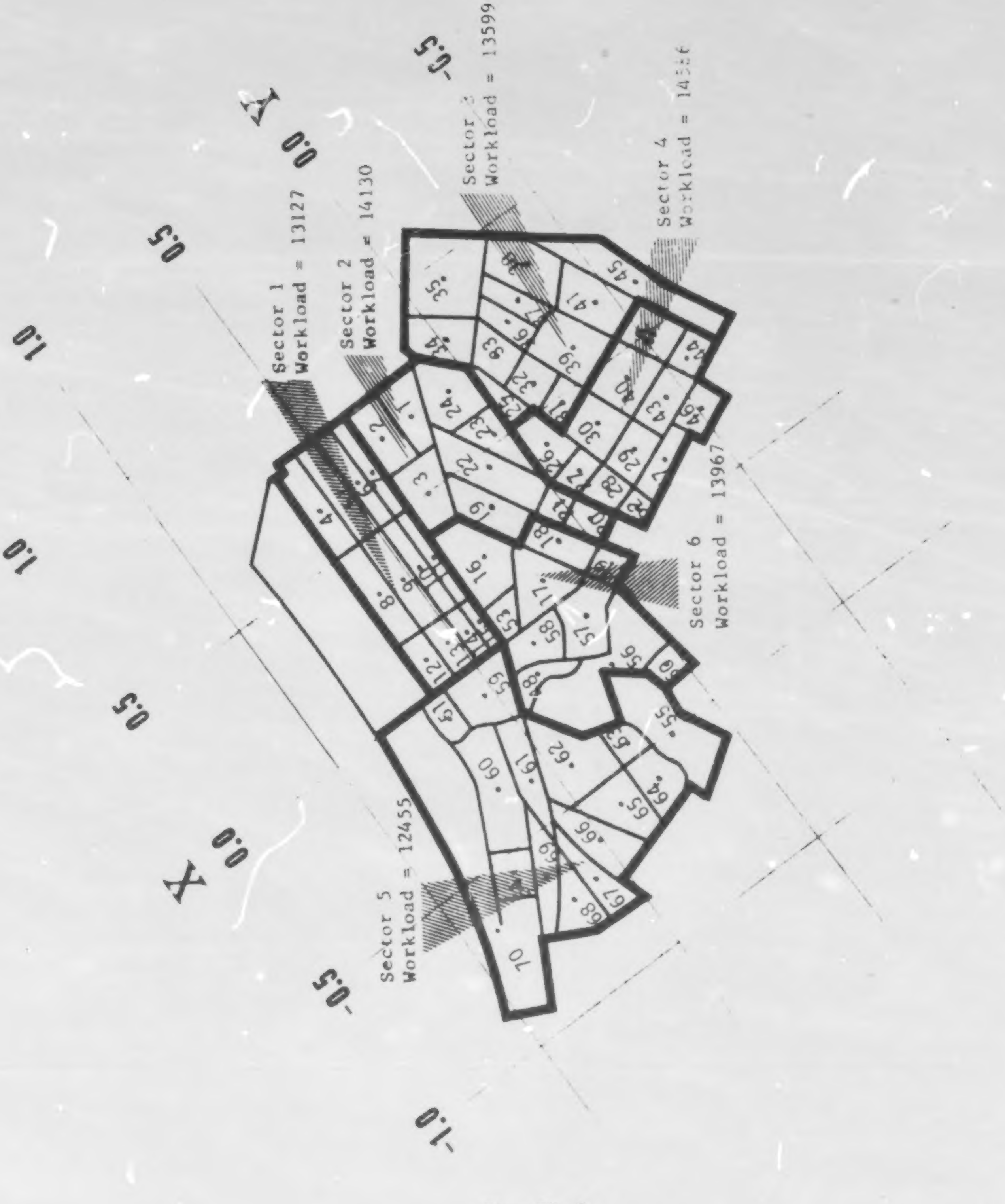

Sector 1
Workload = 13127
Sector 2
Workload = 14130
Sector 3
Workload = 13599
Sector 4
Workload = 143
Sector 5
Workload = 12455
Sector 6
Workload = 13967
X
Y
1.0
0.5
0.0
-0.5
-1.0

Fig. BP-2

Maximum workload imbalance = 26%

Region-wide average travel time = 3.402 minutes

Average travel time for queued calls = 5.178 minutes

Fraction of dispatches that are cross-sector = 0.485

Profile of Patrol Unit Operations

Patrol Unit No.	Workload	% of Mean	Fraction of Dispatches Out of Sector	% of Mean	Average Travel Time
1	0.519	103.8	0.539	111.3	3.432
2	0.559	111.7	0.576	118.7	3.378
3	0.496	99.2	0.477	98.5	3.090
4	0.490	98.0	0.426	87.9	3.180
5	0.428	85.7	0.373	77.0	3.978
6	0.507	101.5	0.487	100.4	3.414

Profile of Sector Operations

Sector Number	Fraction of District's Total Workload	% of Mean	Fraction of Dispatches that are Cross-Sector	Average Travel Time
1	0.160	96.2	0.503	3.312
2	0.172	103.6	0.542	3.120
3	0.166	99.7	0.480	3.324
4	0.178	106.9	0.474	3.258
5	0.152	91.3	0.412	4.218
6	0.170	102.4	0.491	3.258

Fig. BP-3

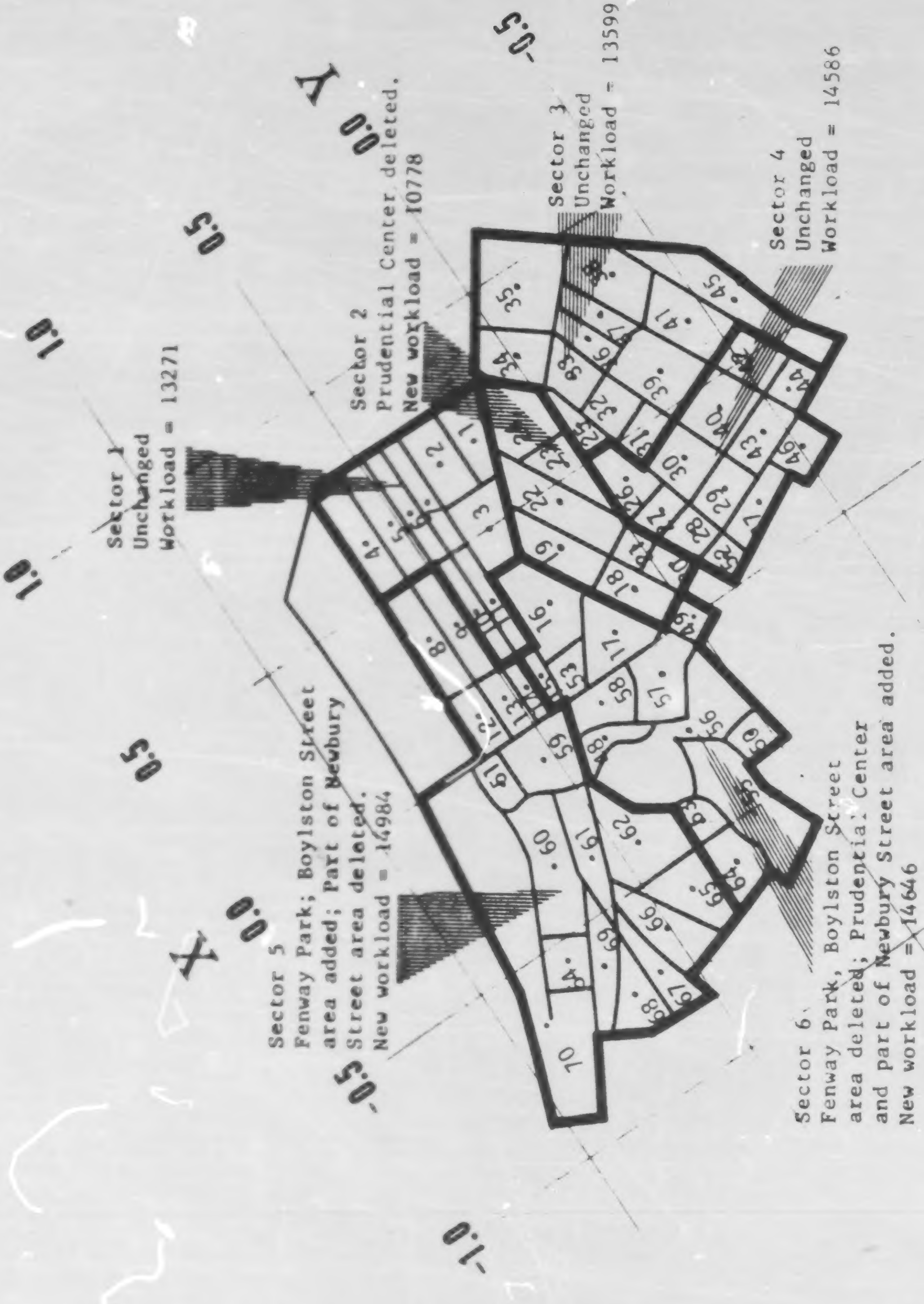

Sector 1
Unchanged
Workload = 13271
Sector 2
Prudential Center deleted.
New workload = 10778
Sector 3
Unchanged
Workload = 13599
Sector 4
Unchanged
Workload = 14586
Sector 5
Fenway Park; Boylston Street
area added; Part of Newbury
Street area deleted.
New workload = 14984
Sector 6
Fenway Park, Boylston Street
area deleted; Prudential Center
and part of Newbury Street area added.
New workload = 14646
X
Y
1.0
0.5
0.0
-0.5
-1.0

Fig. BP-4

Maximum workload imbalance = 5.48%

Regionwide average travel time = 3.426 minutes

Average travel time for queued calls = 5.178 minutes

Fraction of dispatches that are cross-sector = 0.483

Profile of Patrol Unit Operations

Patrol Unit No.	Workload	% of Mean	Fraction of Dispatches Out of Sector	% of Mean	Average Travel Time
1	0.499	99.7	0.495	102.5	3.222
2	0.512	102.4	0.611	126.6	3.318
3	0.497	99.4	0.479	99.3	3.192
4	0.502	100.4	0.453	93.7	3.174
5	0.485	97.0	0.398	82.3	4.074
6	0.505	100.1	0.456	94.5	3.612

Profile of Sector Operations

Sector Number	Fraction of District's Total Workload	% of Mean	Fraction of Dispatches that are Cross-Sector	Average Travel Time
1	0.162	97.3	0.482	2.958
2	0.132	79.0	0.496	2.886
3	0.166	99.7	0.481	3.234
4	0.178	106.9	0.486	3.204
5	0.183	109.8	0.468	4.524
6	0.179	107.3	0.488	3.534

Fig. BP-5

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**For a copy, write to Jan Chaiken at the address given on the last page of this report.

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1. For copies of publications of The New York City-Rand Institute or The Rand Corporation:

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A TRAINING COURSE IN DEPLOYMENT OF EMERGENCY SERVICES: INSTRUCTOR'S MANUAL

PREPARED FOR THE OFFICE OF POLICY
DEVELOPMENT AND RESEARCH, DEPARTMENT
OF HOUSING AND URBAN DEVELOPMENT

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R-1784/1-HUD
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THE
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PREFACE

The development, documentation, and field presentation of this course was performed under a contract with the Office of Policy Development and Research of the U.S. Department of Housing and Urban Development (HUD)--"Contract for the Development, Field Testing, and Documentation of Management Methods for Emergency Services for Local Agencies." This contract and earlier contracts between HUD and The New York City-Rand Institute involved work with city agencies designed to improve the deployment of their emergency service units. Prior to beginning such work, a training course was often presented to agency and city officials and to local analysts.

This course outline provides lesson plans and visual aids for these lectures so that they can be presented by anyone who already understands the subject. References to the appropriate source materials are also provided. Potential audiences for the course include fire service administrators and planning officers, police patrol administrators and planning officers, ambulance agency personnel, city officials, operations research analysts, and mixtures of these groups.

This instructor's manual may also be useful to individuals who wish to undertake a self-directed study of deployment analysis for emergency services. The literature in this field is quite extensive and includes methodological reports, descriptions of computer programs, and case studies of applications of deployment analysis in particular cities. Therefore, it may be difficult for the student to determine which papers are related to the subject he wishes to learn and which ones should be read ahead of others. By following this course outline, it is possible to determine a suitable sequence in which to study the various documents and to gain a general notion of the contents of each of them in advance.

Instructors teaching from this manual may wish to supply copies of the lecture notes to their students, in which case they should order the following companion report from the Publications Department of The Rand Corporation:

R-1784/2-HUD, *A Training Course in Deployment of Emergency Services: Student's Manual.*

The student's manual is not suitable for self-directed study; it should only be ordered in multiple copies for members of a class.

ACKNOWLEDGMENTS

This work was supported by the Office of Policy Development and Research of the U.S. Department of Housing and Urban Development. Many of the lecture notes and visual aids are based on materials developed over a period of several years by our colleagues at The New York City-Rand Institute, and we wish to thank them all:

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In addition, this course was presented in early 1975 to an audience whose members made many helpful suggestions for improving the lecture notes. We especially wish to thank the members of the audience who agreed to serve as a formal evaluation panel for the training course:

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National Fire Protection Association

Lewis Harris
Assistant Chief
Fire Department of the City of New York

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INTRODUCTION

This report has been prepared to assist instructors who wish to present a one- to five-day course in deployment of emergency services. Potential audiences include fire service administrators and planning officers, police patrol administrators and planning officers, ambulance agency personnel, city officials, operations research analysts, and mixtures of these groups. Included are lesson plans, references, and examples of visual aids that can be used.

The authors have tested these outlines by presenting lectures based on them at least once, and several of the lectures have been presented on many occasions in approximately the same form by several members of The New York City-Rand Institute staff.

To prepare a course from the lecture notes, it is necessary to select the lectures that will be presented and the order of presentation. Under no circumstances would all the lectures be given to one audience, since there are pairs of lectures (identified by the same first initial) that cover the same topic from different perspectives. The second initial of the lecture identifier indicates whether it is intended for a fire service audience (F), a police service audience (P), or a general audience (G).

A suitable sequence for a course to be given to a fire service audience in three days (or, preferably, somewhat over five half-days) is as follows:

Lecture OF:	Introduction and Overview
Lecture RF:	Rules of Thumb
Lecture DF:	Data Analysis
Lecture AF:	Allocation of Fire Companies
Lecture LF:	Locating Fire Stations
Lecture SF:	Simulation
Lecture MF:	Relocation or Move-up
Lecture IF:	Initial Dispatch
[Not included]:	Case study of application in some city

For an audience representing several types of emergency service agencies, a suitable sequence at the start of the course is:

Lecture OP: Introduction and Overview (police)
Lecture RP: Rules of Thumb (police)
Lecture CG: Characteristics of Emergency Services

Some lectures have been prepared under the assumption that they will be preceded by certain other lectures. The overview and rules of thumb (either OF and RF or OP and RP) should precede any other lecture; allocation (AF or AP) should precede fire station location (LF) or beat design (BP). Lectures on data analysis and simulation for police audiences have not been included in this report, but lectures DF and SF may be useful to the instructor in preparing materials on these topics.

Each of the lectures has been prepared using the same format. The content of the lecture is preceded by an estimate of the time that the lecture should last, the objective of the lecture, and, if appropriate, a list of special equipment that is needed for the lecture. The outline of each lecture is presented on a page that is divided into two parts. The "Activity" part describes the items to be discussed. The "References and Notes" column refers the lecturer to sources of more information on the subject (the full references are given in the Bibliography at the end of this report), identifies visual aids that might be used at that point, or provides suggestions designed to help the lecturer in his presentation.

We have found that including a lecture describing an actual deployment study that was conducted in some city (preferably delivered by someone from that city) can be very helpful. In fact, the one consistent comment from those who have taken the course was the importance of case studies. If it is not possible to obtain a guest lecturer, one of the case studies indicated by an asterisk (*) in the Bibliography will serve as a starting point for preparing such a lecture. However, someone in the study city should be contacted for the latest developments. Appropriate addresses are given in many of the case studies.

The case study should be selected before the course begins, and some indication of the types of deployment changes that resulted from the study should be presented at an early point, possibly even before Lecture OF or Lecture OP.

Another frequent comment from those who have taken this course concerned the desirability of students having personal copies of the lecture notes. Such notes can be kept in hand during the lecture, thereby eliminating the necessity for the lecturer to prepare slides of the visual aids, or they may be simply a permanent record of the material covered in the course, to be used outside the class. For these purposes we have made available a student's manual as a companion to this report; it differs from this volume only in that all text in the "References and Notes" section of each lecture has been removed. This leaves space for the student to record whatever he feels is appropriate and permits the instructor to select or modify the visual aids and references, since they are not specifically cited in the student's manual.

LECTURE OF

INTRODUCTION AND OVERVIEW
FOR FIRE SERVICE AUDIENCES

Time: Approx. 40 minutes

Objective: To provide an overview of the fire service problems that will be discussed in the course, and to provide an introduction to systems analysis.

Activity	References and Notes
1. INTRODUCTION • Explain nature of course, audience, and objectives • Describe schedule for entire course	
2. DEFINITION OF "DEPLOYMENT ANALYSIS" • Strategic issues -- How many companies on duty .. may vary by time of day or season -- How divided among subregions of city -- Where stations are located -- Nature of vehicles (engines, ladders, foam units, etc.); manning -- Manpower scheduling • Tactical issues -- (Not fireground tactics) -- Number and types of companies dispatched to an alarm .. may vary with time of day, location of alarm, current situation, available information -- Which units to dispatch -- Relocation (move-up) .. when needed .. how many companies move .. which ones move	Follows Chaiken and Larson, Methods for Allocating Urban Emergency Units and Chaiken, Ignall, and Walker, Deployment Methodology for Fire Departments

Activity	References and Notes
3. STEPS IN "SYSTEMS ANALYSIS" (A systematic approach to solving problems) • Identify the problem • Select objectives • Define criteria to be used to evaluate alternative policies • Design alternative policies • Select models to be used • Collect required data • Compare alternatives using criteria • (Return to an earlier step) • Test out and implement final choice	See Quade, Analysis for Public Decisions
4. PROBLEMS • This course will deal with the strategic and tactical issues of deployment analysis	
5. OBJECTIVES May be several. Some of the most common are: • Improve fire protection levels with same resources • Maintain fire protection levels with less resources • Decrease workload while maintaining fire protection levels	

Activity	References and Notes
6. RELEVANT CRITERIA (PERFORMANCE MEASURES) (Used to tell if one policy is better than another policy)	Figure OF-1
• Time until dispatch of companies	Explain each time interval
• Turnout time	
• Travel time -- Can be average or maximum or something else -- To first-arriving company, max (first engine, first ladder), max (all companies needed), or other measures of travel time	
• Setup time	
The above four constitute "response time." Usually must pay attention to the largest one. Deployment analysis focuses on changes that can affect travel time.	
• Coverage measures	
• Workload balance	
• Insurance grading standards?	
• Cost	
Why not lives lost, property lost?	Generally see introduction to Carter and Ignall, *A Simulation Model of Fire Department Operations: Design and Preliminary Results*
• Hard to measure	
• Needs research to be able to estimate changes (relationship not known precisely enough)	
• We use suitable surrogate measures	This issue will be a source of confusion and doubt later, unless handled in sufficient detail at this point

Activity	References and Notes
7. ALTERNATIVE POLICIES	
• Include base case (for comparison)	
• Take political and economic factors into account (including community and labor union concerns)	
• Alternatives may be suggested by fire department or city personnel, or may come from mathematical models	To be discussed next
8. MODELS	
Purpose: To introduce terminology, not to illustrate any particular models	
• Definition: abstraction of reality. Used to gain insight into and answer questions about the real world. Easier, safer, and less costly to use than manipulating real world.	
• Empirical models	
-- Fit to data .. May have no explanation .. May be mathematically complicated	
-- Examples	
.. Smooth fit to alarm rate by time of day	Draw histogram and curve
.. How long to travel a given distance	Draw representative curve, but don't discuss its shape now. Figure OF-2
.. Chance that an alarm at a particular location is serious	

Activity	References and Notes
8. MODELS (continued)	
• Descriptive analytical models	
-- Using simplified assumptions, some kind of mathematical formula is derived to permit estimating some performance characteristic(s)	Figure OF-3
-- The numbers that go into such a model may come from empirical models	
-- Examples .. Knowing number of engines and ladders on duty, estimate average response distance .. Knowing where fires are and how many units dispatched, estimate number of responses for each unit (workload) .. If fire station is moved, what happens to response time	
• Optimization models (prescriptive)	
-- Tell how to achieve the most or the least of something	
-- Examples .. What is the least number of engine stations needed so that each location is within 3/4 mile of a station? .. How should 17 stations be located so as to minimize average response time? .. What is the smallest number of engines needed to relocate on a second alarm (if specified coverage is to be achieved)?	

Activity	References and Notes
8. MODELS (continued)	
• Simulation models	
-- Imitate operations step by step	
-- Collect all kinds of statistics	
-- Can be extremely accurate	
-- Doesn't tell you what to do	
-- Things you try will be suggested by other models	
-- Likely not to be useful until close to the end of analysis; but have to start early to collect data	
9. TECHNICAL ASSISTS TO DEPLOYMENT	These are examples of items not discussed further in this course
• Computer-assisted dispatch	
• Digital communication with fire units	
-- Status	
-- Inspection information	
-- Location of fire, hydrants, etc.	
-- Screen or printer	
• Packaged systems for collecting, summarizing, or projecting alarm rate information	

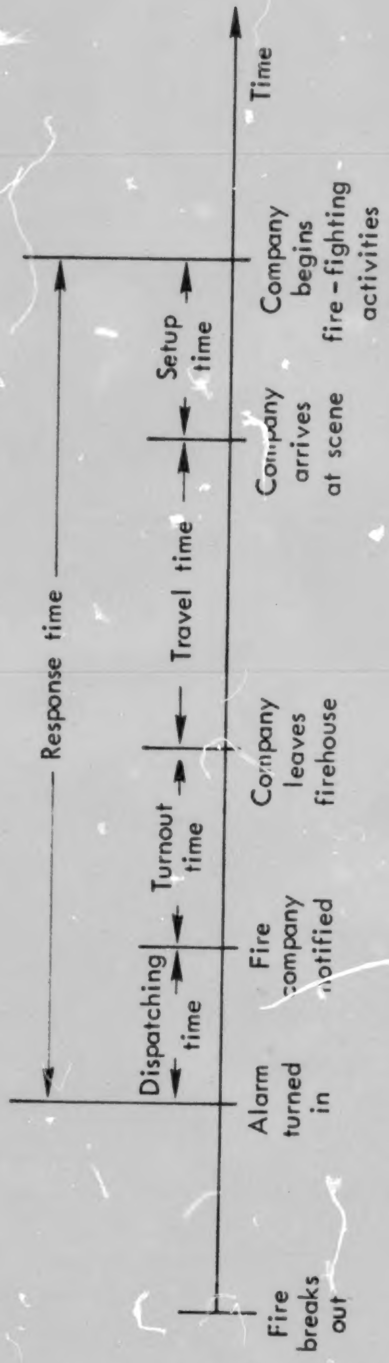
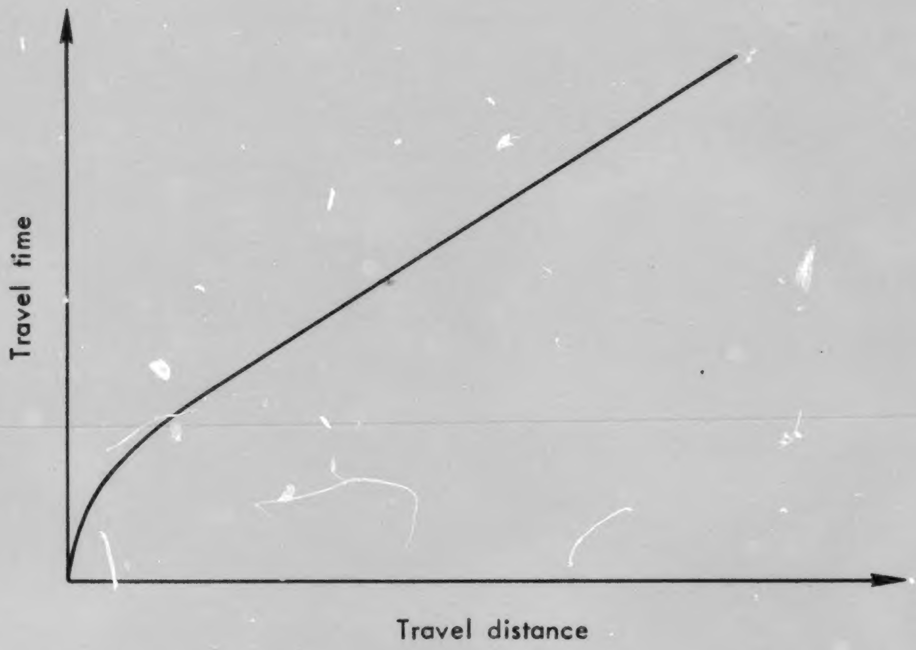

Fire breaks out
Alarm turned in
Fire company notified
Company leaves firehouse
Company arrives at scene
Company begins fire-fighting activities
Time
Dispatching time
Turnout time
Travel time
Setup time
Response time

Fig. OF-1



NOTE: The scale on each axis will vary from city to city

Fig. OF-2

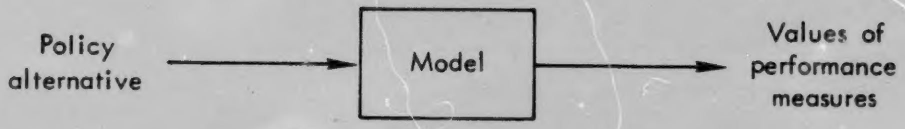

Policy alternative
Model
Values of performance measures

Fig. OF-3—The role of a descriptive model in deployment analysis

LECTURE RF

RULES OF THUMB
FOR FIRE SERVICE AUDIENCES

Time: Approx. 50 minutes

Objective: To provide some easy to learn, easy to apply formulas and rules used in deployment analysis.

Activity	References and Notes
1. AVERAGE NUMBER OF COMPANIES BUSY	This lecture continues to follow Chaiken, Ignall, and Walker, Deployment Methodology for Fire Departments

$$= \left(\begin{array}{c}\text{AV. NUMBER}\\ \text{OF ALARMS}\\ \text{PER HOUR}\end{array}\right) \times \left(\begin{array}{c}\text{AV. NUMBER OF}\\ \text{COMPANY-HOURS}\\ \text{PER ALARM}\end{array}\right)$$

- Example

  4 alarms per hour (all types)
  30 minutes average time out-of-service
  1.2 engines per alarm, average

  4 x (0.5 x 1.2) = 2.4 engines busy on average

- AVERAGE NUMBER OF COMPANIES AVAILABLE = TOTAL NUMBER OF COMPANIES − (AVERAGE NUMBER BUSY)

2. $\left(\begin{array}{c}\text{AVERAGE TRAVEL DISTANCE}\\ \text{in a region}\end{array}\right) =$

$$(\text{CONSTANT}) \times \sqrt{\frac{\text{AREA OF REGION}}{\text{NO. COMPANIES AVAILABLE}}}$$

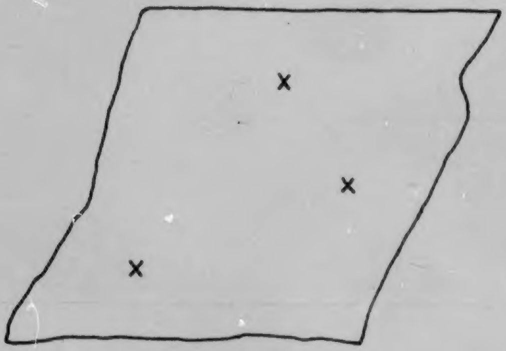
- Introduce notion of square root simply, via $3^2 = 9$ and therefore $\sqrt{9} = 3$

Ref.: Kolesar and Blum, Square Root Laws for Fire Company Travel Distances

Activity	References and Notes
2. AVERAGE TRAVEL DISTANCE (continued)	
• Give simple geographical demonstration showing why the rule of thumb is true	The following should be prepared as slides that can be overlaid
-- Base case	Figure RF-1
-- Double all dimensions: area quadruples, average travel distance doubles (i.e., goes up by square root of area)	Figure RF-2
-- Repeat region 4 times: same area as in RF-2 with quadruple the companies, average travel distance is only halved (i.e., goes down as the square root of the number of companies)	Figure RF-3 Argument is not exact; don't get into details at this point
-- Halve all dimensions in RF-3: same area as RF-1 with quadruple the companies, average travel distance is halved (shows how hard it is to decrease travel times by adding companies; to halve travel times must quadruple the number of companies)	Figure RF-4
• Number of companies available changes from time to time. If the average number available in a region is not too small, the average travel distance can be estimated by replacing "NO. COMPANIES AVAILABLE" with "AV. NO. COMPANIES AVAILABLE."	Now averaging over time as well as geography
• Note that this relationship assumes companies are spread out in region. Two companies in one house reduce by one the effective number of companies available (for travel distance purposes)	Although $E(\sqrt{N}) \neq \sqrt{E(N)}$ the error is small. See Kolesar and Blum, Square Root Laws for Fire Company Travel Distances, p. 51
• This is an example of an analytical model that has been verified against data	

Activity	References and Notes
3. RELATIONSHIP OF TRAVEL TIME TO TRAVEL DISTANCE • Travel time is an important criterion for evaluating deployment policies; it is clearly related to travel distance, but how	Ref.: Kolesar and Walker, Measuring the Travel Characteristics of New York City's Fire Companies
• This is an example of an empirical model	
• Show usual shape of curve--square root blending into a straight line	Figure OF-2
• Discuss underlying model of acceleration to cruise speed and then deceleration (no equations)	This relationship will be discussed in more detail in Lecture LF
• Emphasize that if you extend the straight line to the axis, it looks as if turnout time is included, but that's not what's happening	

Activity	References and Notes
4. ALARMS DO NOT OCCUR AT ORDERLY, PREDICTABLE TIMES, AND SERVICE TIMES DO NOT ALWAYS EQUAL THE AVERAGE (If they did, deployment analysis would be easy)	
Purpose: To introduce probabilistic notions, and suggest that mathematical models "understand" that sometimes the situation can be much worse than average	
• If average number of alarms is 2 per hour at a certain time of day (such as Friday, 4-6 p.m.), then	Use an example that will "seem right" to your audience
14% of such hours will have no alarms 27% of such hours will have 1 alarm 27% of such hours will have 2 alarms	Ref.: Any table of the Poisson distribution
18% of such hours will have 3 alarms 9% of such hours will have 4 alarms 5% of such hours will have 5 or more alarms	Mention "Poisson process" only in response to questions, like "How do you know?"
• Discuss what "x% of hours" means	
• 2 alarms (the average) is not even more likely to occur than 1 alarm	
• There are influences other than random that can make some Friday nights especially busy or quiet -- Weather (e.g., brush fires) -- Holiday (e.g., July 4)	Don't discuss in detail. This is discussed further in Lecture DF

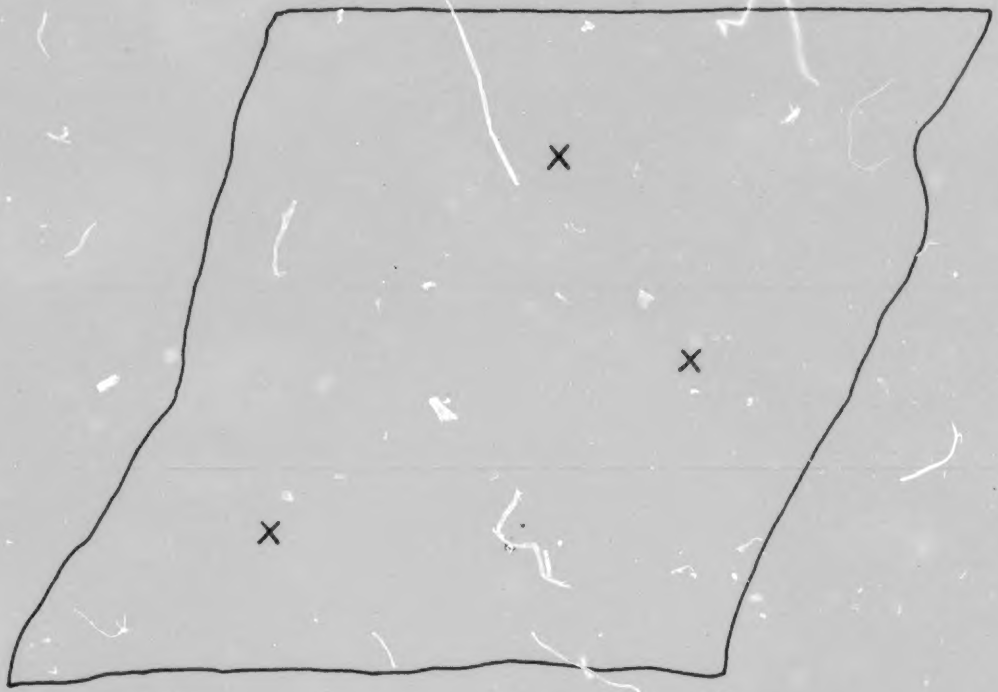


Average travel distance = D

Area = A

Number of units = N (3)

Fig. RF-1

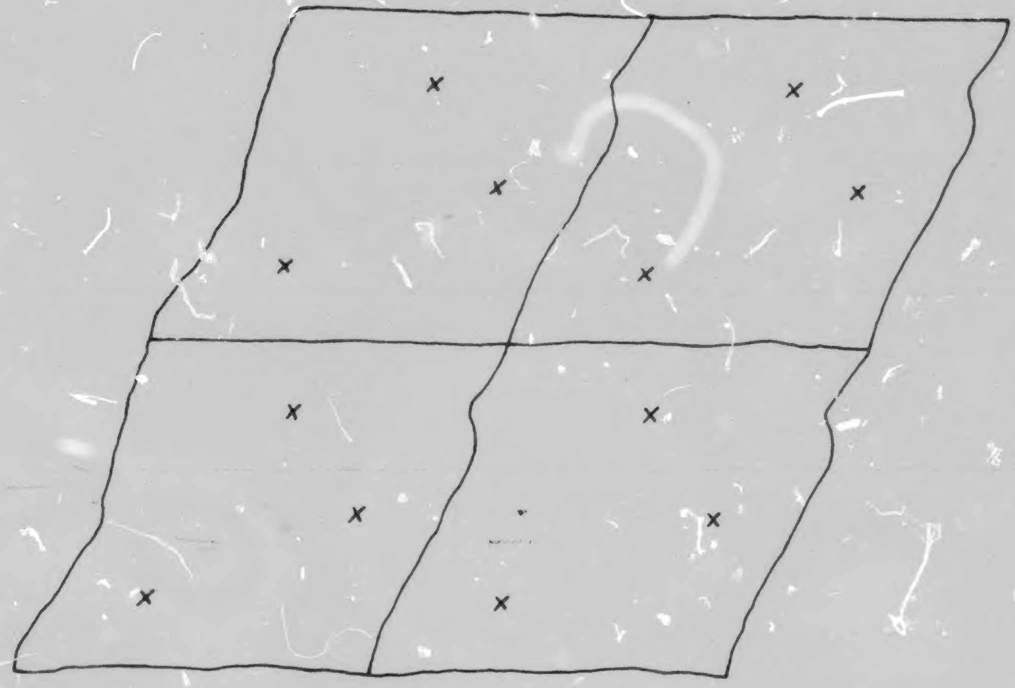


Area = 4A

Average travel distance = 2D

Number of units = N

Fig. RF-2

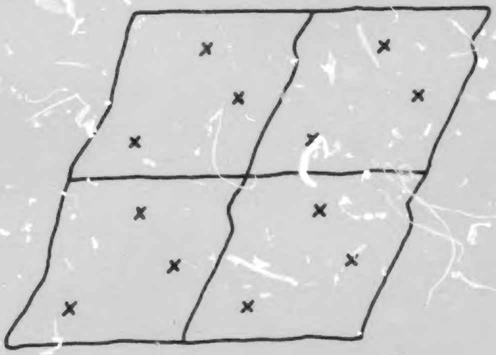


Average travel distance = D

Area = 4A

Number of units = 4N

Fig. RF-3



Average travel distance = 1/2 D

Area = A

Number of units = 4N (12)

Fig. RF-4

LECTURE OP

INTRODUCTION AND OVERVIEW FOR POLICE SERVICE AUDIENCES

Time: Approx. 40 minutes

Objective: To provide an overview of the police patrol resource allocation problems that will be discussed in the course, and to provide an introduction to systems analysis

Activity	References and Notes
1. INTRODUCTION	Follows Chaiken, Patrol Allocation Methodology for Police Departments
• Explain nature of course, audience, objectives	
• Describe schedule for entire course	
2. DEFINITION OF "PATROL"	
• Uniformed officers in mobile vehicles who can respond to calls for service	

Activity | References and Notes

3. DEFINITION OF "ALLOCATION"

- How many men on duty
  - -- Varies by day and time of day
- Mode of patrol
  - -- One-man cars
  - -- Two-man cars
  - -- Scooters
- How many units in each geographical command
- Design of patrol beats for each unit
- Priorities attached to different types of calls (screening)
- When calls are queued (stacked, backlogged)
- Number of units dispatched
  - -- Varies with location and type of calls
- Which units dispatched
  - -- Type
  - -- Closest unit?
  - -- Beat car?
  - -- Across command boundaries?
- Redeployment as unavailabilities occur
- Manpower scheduling
- Scheduling of "other" unavailabilities

Activity	References and Notes
4. STEPS IN "SYSTEMS ANALYSIS" (A systematic approach to solving problems)	See Quade, Analysis for Public Decisions

- Identify the problem
- Select objectives
- Define criteria to be used to evaluate alternative policies
- Design alternative policies
- Select models to be used
- Collect required data
- Compare alternatives using criteria
- (Return to an earlier step)
- Test out and implement final choice

5. PROBLEMS

- This course will deal with the problems associated with the allocation of police patrol resources

6. OBJECTIVES
May be several. Some of the most common are:

- Improve police protection levels with same resources
- Maintain police protection levels with less resources
- Improve the balance of workload among patrol units

Activity	References and Notes
7. CRITERIA (PERFORMANCE MEASURES)	
• Length of time caller must wait until unit is dispatched	
• Travel time to scene	
• Dispatches out of assigned area	
• Balance of workload among units	
• Time available for other activities	
-- Preventive patrol	
-- Meals	
-- Patrol-initiated investigation	
-- Traffic	
-- Maintenance of vehicle	
-- Interaction with citizens	
• Cost	
• Why not crime deterrence, apprehension of criminal offenders, recovery of stolen property, community sense of security?	
-- Hard to measure	
-- Relationship to allocation not known precisely enough	Some doubt of the value of preventive patrol. See Kelling, et al., The Kansas City Preventive Patrol Experiment
-- We use proxy measures	
-- Administrators can tell what changes in performance measures (up or down) are desirable, even if they don't know the exact benefit	
8. ALTERNATIVE POLICIES	
• Include existing policy (for comparison)	
• Take political and economic factors into account (including community and labor union concerns)	
• Alternatives may be suggested by police department or city personnel, or may come from mathematical models	Discussed next

Activity	References and Notes
9. MODELS	
Purpose: To introduce terminology, not to illustrate any particular models	
• Definition: abstraction of reality. Used to gain insight into, and answer questions about, the real world. Easier, safer, and less costly to use than manipulating real world	
• Empirical models	
-- Fit to data .. May have no explanation .. May be mathematically complicated	
-- Examples	
.. Smooth fit to call rate by time of day	Draw histogram and curve
.. How long to travel a given distance	Draw representative curve, but don't discuss its shape now. Figure OF-2
.. Relationship between fraction of time cars are unavailable and number of calls for service	
• Descriptive analytical models	
-- Using simplified assumptions, some kind of mathematical formula is derived to permit estimating some performance characteristic(s)	Figure OF-3
-- The numbers that go into such a model may come from empirical models	
-- Examples .. Knowing number of units on duty, estimate average travel time to an incident .. Knowing number of units on duty, estimate fraction of serious emergencies encountering a delay before dispatch .. Knowing the patrol area of each unit and location of incidents, estimate workload and fraction of out-of-district dispatches for each unit	

Activity

References and Notes

9. MODELS (continued)

- Optimization models (prescriptive)
  - -- Tell how to achieve the most or the least of something
  - -- Examples
    - .. How should sectors be designed to minimize average travel time to incidents?
    - .. How should a fixed total number of man-hours be distributed among tours so as to minimize the chances that a caller will have to wait before dispatch of a patrol car?
- Simulation models
  - -- Imitate patrol operations step by step
  - -- Collect all kinds of statistics
  - -- Can be extremely accurate
  - -- Don't tell you what to do
  - -- Things you try will be suggested by other models
  - -- Likely not to be useful until close to the end of analysis; but have to start early to collect data

LECTURE RP

RULES OF THUMB
FOR POLICE SERVICE AUDIENCES

Time: Approx. 80 minutes

Objective: To provide some easy to learn, easy to apply formulas and rules used in police patrol resource allocation analysis

Activity	References and Notes
1. AVERAGE NUMBER OF UNITS BUSY HANDLING CALLS FOR SERVICE $= \begin{pmatrix}\text{AVERAGE NUMBER}\\ \text{OF CALLS}\\ \text{PER HOUR}\end{pmatrix} \times \begin{pmatrix}\text{AVERAGE}\\ \text{UNIT-HOURS}\\ \text{PER CALL}\end{pmatrix}$ • Give an example [illegible] calls per hour, average 1 car handles each Average length of time to handle call, 30 minutes On the average, 1 car is busy If 2 cars on duty, each is busy $\frac{1}{2}$ the time If 4 cars on duty, each is busy $\frac{1}{4}$ the time • Number of units on duty must at least equal average number busy	This lecture continues to follow Chaiken, Patrol Allocation Methodology for Police Departments

Activity | References and Notes

2. EMERGENCIES DO NOT OCCUR AT ORDERLY, PREDICTABLE TIMES, AND SERVICE TIMES ARE NOT THE SAME FOR ALL CALLS
(If they did, the analysis would be easy)

- Example:

  -- Calls occur on the hour and half-hour. Every call takes exactly 30 minutes

  1 car can handle--nobody waits
  --but car is always busy

  If 2 cars--nobody waits
  --each car is free half the time
  --always one car on patrol

  -- But, when average number of calls is 2 per hour

  Ref.: any table of the Poisson distribution

  14% of hours have no calls
  27% of hours have 1 call
  27% of hours have 2 calls
  18% of hours have 3 calls
  9% of hours have 4 calls
  4% of hours have 5 calls
  1% of hours have 6 or more calls

  -- Considering the usual spread of service times around 30 minutes

  With 1 car on duty, every caller waits

  With 2 cars on duty,
  1/3 of callers wait
  1/3 of time no car is on patrol
  Average wait until a car can be dispatched is 10 minutes (incl. no-wait)
  17% of callers wait more than 20 minutes

- Conclusion: Number of units on duty must be considerably more than average number busy

Activity | References and Notes

3. A MINIMAL STANDARD FOR ADEQUATE PERFORMANCE IS: NO MORE THAN 15% OF IMPORTANT CALLS ARE QUEUED

- Many departments don't achieve this (especially during peak hours)
- A goal set by some departments is: No more than 5% of important calls are queued
- A few departments routinely have less than 1% of important calls queued
- Impossible to guarantee that no calls will be queued

4. CARS ARE UNAVAILABLE FOR DISPATCH FOR REASONS OTHER THAN RESPONSE TO PREVIOUS CALLS

- What are these activities?
  - Meals, personal
  - Patrol-initiated crime or vehicle check
  - Notifications, warrants
  - Process arrestee
  - Supervision - field
  - Supervision - station
  - Waiting
  - Travel to assigned beat
  - Transport (something)
  - Assigned to fixed location
  - Maintenance, auto
- Ordinarily, at least 30 percent of each unit's time spent on such unavailabilities
- In San Fernando Valley area of Los Angeles, average unavailabilities vary among divisions from 44% to 62% of total time on duty. In one New York precinct, 58 percent

Ref.: Analysis of the Los Angeles Police Department's Patrol Car Deployment Methods, UCLA School of Engineering Technical Report

- For queuing purposes, effective number of units on duty may be less than half the number assigned

Activity	References and Notes
5. NUMBER OF UNITS NEEDED TO MEET DESIRED LEVEL OF QUEUING DOES NOT INCREASE PROPORTIONATELY WITH NUMBER OF CALLS	
• Example: A command with 2 calls per hour needs 7 units. This is not twice the number needed in a command with 1 call per hour (namely, 5 units)	Figure RP-1
6. AVERAGE NUMBER OF MINUTES BETWEEN PASSINGS OF A RANDOM POINT BY UNIT ON PATROL ≈ $6 \times \frac{\text{NUMBER OF STREET MILES IN BEAT}}{\text{FRACTION OF TIME AVAILABLE}}$	Ref.: Larson, Urban Police Patrol Analysis
• Nobody has proved from data that preventive patrol deters crime	
• Mention Kansas City Proactive-Reactive Patrol Experiment	Ref.: Kelling et al., The Kansas City Preventive Patrol Experiment Ref.: Press, Some Effects of an Increase in Police Manpower in the 20th Precinct of New York City

Activity	References and Notes
7. AVERAGE TRAVEL TIME $\approx$ 2 min $\sqrt{\frac{\text{AREA (in sq miles)}}{\text{NO. UNITS AVAIL.}}}$	Ref.: Kolesar and Blum, Square Root Laws for Fire Company Travel Distances
• Example: Area of command is 6 square miles 5 patrol cars on duty Each available 60% of time Average travel time $\approx$ 2 min $\sqrt{6/3}$ = 2.83 min	
• Why this is a general principle	Use Figures RF-1 to RF-4 (see Lecture RF for accompanying text)
• Total response time = (dispatching delay) + (queuing delay) + (travel time)	
• Reducing response time increases probability of apprehending offender at the scene, but the effect is important only if very short response times can be achieved	Ref.: Clawson and Chang, Relationship Between Response Time and Call Disposition
• Reducing travel time can help to reduce response time into the useful range if queuing delays are short. It makes no sense to reduce travel times when queuing delays are long	

Activity

8. WHAT CAN YOU DO WITH PRIORITIES?

- If queue forms, dispatch free unit to oldest highest priority call
    - -- Average delay the same
    - -- Delay for high-priority calls is less
- Hold one or two units in reserve for high-priority calls
    - -- Regular beat car
    - -- Special unit
    - -- Average delay is more
- Screen out low-priority calls when busy
    - -- "Adaptive dispatch policy"
- Schedule low-priority calls for handling at a more convenient time

9. WHAT'S WRONG WITH $\left\{\begin{matrix}\text{WORKLOAD}\\ \text{HAZARD}\end{matrix}\right\}$ FORMULA?

- Description of Hazard Formula
    - -- $F_j = j^{th}$ factor
    - -- Examples:

      Number of outside violent crimes
      Number of other Part I crimes
      Number of street miles
      Number of arrests
      Number of commercial establishments
      Number of emergency calls
    - -- f_{ij} = amount of factor j in command i
    - -- $F_j = f_{1j} + f_{2j} + f_{3j} + \dots + f_{Nj}$
    - -- w_j = "importance" of factor j
    - -- $H_i = w_1 \frac{f_{i1}}{F_1} + w_2 \frac{f_{i2}}{F_2} + \dots + w_M \frac{f_{iM}}{F_M}$
    - -- Manpower proportional to H_i

References and Notes

Refs.:
Chaiken and Larson, Methods for Allocating Urban Emergency Units

Kakalik and Wildhorn, Aids to Decisionmaking in Police Patrol

Chaiken, Patrol Allocation Methodology for Police Departments

Activity

9. WHAT'S WRONG WITH $\left\{\begin{matrix}\text{WORKLOAD}\\\text{HAZARD}\end{matrix}\right\}$ FORMULA? (continued)

- Description of Workload Formula
  - -- w_j = number of man-hours associated with factor j
  - -- $H_i = w_1 f_{i1} + w_2 f_{i2} + \ldots + w_M f_{iM}$
  - -- Manpower proportional to H_i
  - -- Mathematically the same as Hazard Formula with different weights
- Problems
  - -- Apples and oranges
  - -- Interrelated
  - -- Proportional increase for emergency calls
  - -- No way to determine "correct" weights for Hazard Formula
  - -- Workload Formula accomplishes only one objective: equalizing workload
  - -- Hazard Formula does not do what it appears to do

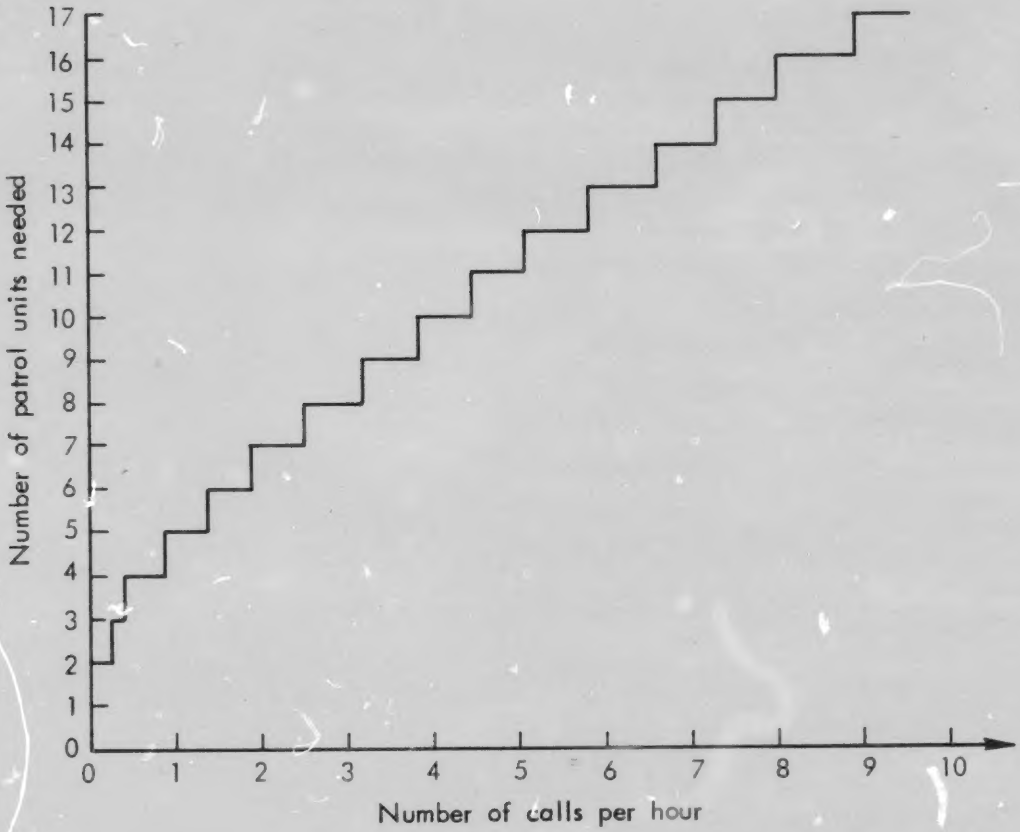
    Example: Assume precincts with high numbers of outside crimes have proportionately more unimportant calls. Then increasing w_j for outside crimes decreases manpower assigned to high-crime precincts
  - -- No credit for good performance
- May be useful for manpower needs other than patrol

References and Notes

For example, a call may be a Part I crime

In the example, the hazard formula is assumed to include the factors "outside crimes," "other calls for service," and possibly other uncorrelated factors

Number of patrol units needed so
that at most 10% of calls delayed



Assumptions: 30 minute service time per call
50% of each car's time spent
unavailable for reasons other than dispatch to a call

Fig. RP-1

LECTURE CG

CHARACTERISTICS OF EMERGENCY SERVICES FOR GENERAL AUDIENCES

This lecture is intended for audiences of analysts interested in the similarities and differences among emergency services and for audiences containing a mixture of fire, police, and ambulance service representatives.

Time: Approx. 60 minutes

Objective: To describe the general characteristics of emergency services that are relevant for deployment analyses

Activity	References and Notes
1. INTRODUCTION • Some models developed for one emergency service can be applied directly to another service, changing only terminology. Others are unique to a particular service because of distinct characteristics • Considering only police patrol, fire units, and emergency medical services	Generally, the lecturer must be familiar with the references in Lectures OF, IF, OP, and IP
2. CALLS FOR SERVICE • Arrival process All three services: Poisson by time and geography. Rate varies by hour about an order of magnitude. Any method that predicts demands for one service will also work for others • Priority structure Police and ambulance: priorities can be identified; some calls are not time-urgent; some calls can be rejected when necessary to prevent system congestion, but there may be legal constraints on call rejection Fire: information for distinguishing type of call may be absent (e.g., street box alarm); when present, information does not determine priority, but only the number and type(s) of units needed	In working on blackboard, this and following items can be organized by heading three columns "police," "fire," and "ambulance"

Activity | References and Notes

3. TYPES OF UNITS

Police: usually all patrol units are interchangeable from the point of view of the functions they can perform when they reach the scene

Fire: at least two types: engines and ladders; limited interchangeability

Ambulances: may have distinguishable capabilities: transport only, routine treatment, or intensive care (medic units, mobile cardiac care units)

4. MANNING

Police: 1 or 2 officers. If both types are present in same city, two 1-man units may be needed as an alternative to one 2-man unit

Fire: 3 to 7 fire-fighters

Ambulance: standard is now 2 attendants; some agencies do not achieve this

5. LOCATION OF UNITS

Police: mobile. Patrol areas can in principle be designed in any way desired, but administrative constraints are often imposed. Patrol areas can also change during or between tours of duty, but this is becoming less common with the advent of "neighborhood teams." Overlap of sectors possible, but not done in most cities. Geometrical probability models for two or more randomly located points relevant

Fire and ambulance: usually fixed locations. "Patrol" activities such as inspection infrequent; can ignore in most cities. May be several units at one location. Type of physical structure not important for ambulances (garage, hospital, police station, fire station). Fixed location implies "turnout" time

Activity	References and Notes
6. HOW MANY UNITS ON DUTY	
Police and ambulance: flexible by day and time	
Fire: usually not varied over the day; a long-term planning issue	
7. QUEUING OF CALLS DUE TO UNAVAILABILITY OF UNITS	
Police: common in many cities. Wait may dominate travel time. Queue usually has priority structure in practice	
Ambulance: common in a few cities. Happens occasionally in many cities	
Fire: Only under crisis conditions. Not relevant for deployment analysis	
8. HOW MANY UNITS DISPATCHED	
Police: usually one. For some calls two 1-man cars are dispatched. In practice, more units may respond than are dispatched	
Fire: usually at least two. In some cities as many as 5-7. Traditionally preplanned according to: (a) nature of land use (business, residential, high rise) (b) nature of incident	
Analysis can consider time of day, projected incidence rates, current unavailability status of system, probability that incident is serious, manning on unit	Ignall et al., Improving the Deployment of New York City Fire Companies
Ambulance: usually one. Some systems dispatch two or three, having different capabilities (a) First responder has limited capabilities; second has full treatment and transport capabilities (b) First has full treatment capabilities but cannot transport; second can transport	Ignall and Urbach, The Relationship Between Fire-Fighting Unit Availability and the Number of Units Dispatched

Activity	References and Notes
9. WHICH UNIT(S) DISPATCHED	
Police: usually sector car if available. If not available, several policies are possible	See MCM, SCM, etc., in Larson, *Urban Police Patrol Analysis*, or in Larson, *Hypercube Queuing Model: User's Manual*
Fire: traditionally preplanned. Almost always closest available, on initial dispatch	Describe alarm assignment card. Explain how this is equivalent to specifying a response area for each unit. See Lecture IF
Analysis shows this may not be optimal	Carter, Chaiken, and Ignall, *Response Areas for Two Emergency Units*
10. RELOCATION	
Fire: traditionally preplanned for multiple-alarm fires. May be needed for several simultaneous smaller fires. Explain purpose	See Lecture MF
Police and ambulance: rarely used, but would have same benefits as in fire case	
11. UNAVAILABILITY FOR REASONS OTHER THAN PREVIOUS DISPATCH	
Fire and ambulance: recovery from previous incident only	
Police: substantial part of activity. May amount to 35%-60% of time. Some of these unavailabilities could be interrupted by high-priority incident	

Activity	References and Notes
12. PERFORMANCE CRITERIA	
(a) Queuing concepts Fire: delays by dispatchers; probability that all or most units assigned to a subarea will be busy Police and ambulance: dispatch delays, expected time in queue, probability of waiting > T in queue, delays by priority level	
(b) Travel time Fire: is a vector (by order of arrival and type of unit) Police and ambulance: relevant for certain calls	
(c) Turnout time Fire and ambulance	
(d) Workload balance All three	
(e) Dispatches out of usual area Police	For other services, this is of interest only by virtue of its effect on travel time and workload balance
(f) Time available for nondispatch functions Police	
(g) Cost of operation All three	

LECTURE DF

DATA ANALYSIS
FOR FIRE SERVICE AUDIENCES

Time: Approx. 60 minutes

Objective: To introduce students to types of alarm patterns and their usefulness, and to suggest approaches for analyzing data.

Activity	References and Notes
1. DEFINITION OF DATA ANALYSIS	Lecture continues to follow Chaiken, Ignall, and Walker, *Deployment Methodology for Fire Departments*
• Emphasize the view of discovering patterns that allow deployment to be improved	
• Indicate that variation is expected, otherwise play it down	Figure DF-1, on the blackboard
• Give example of a nonuseful pattern (Thursday is Tacoma, Washington's slowest day)	
• Say that usual computer reports are not sufficient for data analysis, although possibly useful for management purposes	
2. COMMON PATTERNS--THEIR RELIABILITY AND USE	
• Let the audience help identify and classify them	Figure DF-2, on the blackboard
• Do geography, type of incident, trend, season, day of week, time of day (optional--weather)	
• Structural fires may have different patterns than false alarms; patterns of total alarms, structures, and false alarms will all be illustrated	

Activity	References and Notes
3. HAZARD REGIONS (Also called demand regions)	
• Indicate need for dividing city into regions	
• Characterize a good definition	
-- Start with a description of an ideal (fictional) region: uniformity of land use, alarm patterns, structures, etc.	
-- Less variation within regions than between regions	
-- End with the notion that the division into regions is successful if no one feels they should ask, "But are response times in the north part of the region higher or lower than in the south?"	
-- May be convenient to have each hazard region be a set of company administrative areas or census tracts	
• Display alarms per capita and alarms per square mile and indicate their use	Figures DF-3, DF-4
-- Trend prediction (if population trend can be predicted)	
-- Allocation model	See Lecture AF
4. TIME-OF-DAY PATTERN	
To illustrate a common pattern and statistical variability around it	
• Display hourly total alarms over a period of several days. Indicate	Figure DF-5
-- consistency (evening always higher than late night)	
-- variation around it	
• Optional: July 4 vs. average vs. slow day	Figure DF-6
• Offer weather as a partial explanation of the variation	Figure DF-7 (may be omitted) Figure DF-8
• Ask audience for possible uses--different number of men on duty at different hours, etc. Emphasize possible--they may not be desirable uses.	

Activity	References and Notes
5. TREND AND SEASON	
To illustrate superposition of patterns and how to untangle effects	
• Display a short pattern, indicate inadequacy (total alarms, 34 months, Tacoma)	Figure DF-9
• Display a long pattern (false alarms, 60 months, New York City)	Figure DF-10
• Display detrended seasonal pattern -- Indicate that slide shows ratio of alarms in a week to the trend -- Could calculate the difference between alarms in a week and the trend as alternative -- Stress the economy of the ratio description	Figure DF-11
• Ask audience for possible uses	
6. PATTERN "SIZE"	
To indicate the possible usefulness of a pattern	On the blackboard. using Figures DF-9, DF-12
• Divide previous patterns into 4 seasons and 4 six-hour periods (divide the year and the day into the same number of parts, in this case, 4)	Figure DF-13
• Calculate ratio of peak period to low period for each of the two patterns	
• Compare the ratios. A big ratio indicates a pattern possibly worth trying to take advantage of	
• Check statistical significance of large ratios -- if ratio is large, but the data do not establish significance, gather more data -- [if a small ratio is statistically significant, there may nonetheless be no policy value to the pattern]	

Activity	References and Notes
7. GEOGRAPHICAL PATTERNS--LARGE AREAS	
• Illustrate approximate constancy of false alarms as a fraction of box alarms throughout New York City	Figure DF-14
• Stress the economy of this constancy, as it relates to false alarms per capita or per square mile, which vary even more than total alarms illustrated in Figures DF-3, DF-4	
8. GEOGRAPHICAL PATTERNS--SMALL AREAS	
Purposes: To indicate that part of the data should be reserved, and used for judging the reliability of any patterns discovered and to show a pattern that was discovered because deployment models suggested that if it existed, it would be useful	
• Illustrate box-to-box variability in proportion of all alarms that are false -- Not inconsistent with large area pattern, since no area is exclusively high or low in regard to percent false -- Indicate the pattern is useful only if it is consistent from year to year	(Colored map, not reproducible in these lecture notes, is available from address given on last page of this report. Map shows wide range in percent false at a box. Boxes with high percent false appear isolated, not part of a pattern)

Activity	References and Notes
8. GEOGRAPHICAL PATTERNS--SMALL AREAS (continued)	
• Illustrate the finding and checking of the pattern of box-to-box variations in proportion of box alarms that are serious	Figure DF-15
-- These are year-round numbers	
-- Box 2277 is among the lowest in predicted percent structural, box 2209 is among the highest. But they are not outliers	Ignall et al., *Improving the Deployment of New York City Fire Companies*, Section II
-- Indicate how risk classes were defined	Carter and Rolph, *New York City Fire Alarm Prediction Models: I. Box-Reported Serious Fires*, Section 3.4
-- Stress the role of reserving some of the data	
-- Deployment models shifted attention to serious fires rather than total alarms	
-- Seriousness needs careful definition, specific to the city. Depends on the purpose: Maybe all structural, maybe only those that work several companies, etc.	See Figure DF-18 and Lecture IF
-- The pattern is useful when the alarm rate is high	
• Indicate that season and time of day affect the pattern	
-- Relatively more false alarms in summer (and evening), structural fires almost constant	Figures DF-16, DF-17
-- Serious fires are a larger proportion of structural late at night, in winter (fewer food-on-stove-type incidents)	Figure DF-18
-- Illustrate the size of the overall effect: risky boxes, late night, winter vs. nonrisky, summer evening	
-- *Optional*: Illustrate economy and good fit of separate, multiplicative seasonal and time-of-day factors	Figures DF-19, DF-20

Activity	References and Notes
9. Optional: THE POISSON PROCESS	
Purpose: To introduce probabilistic notions, and suggest that mathematical models "understand" that sometimes the situation is much worse than average	
Suggest its nature and reasonableness. Take a finite set of "similar" hours and a fixed total number of alarms, and discuss distributing the alarms at random. ("Throwing darts at the line")	
• Example--Jersey City. Very small seasonal effect (similar to Tacoma). In 1973, 1480 alarms in 2-4 p.m. period, which is 365 x 2 = 730 hours. In that period, 1480/730 = 2 alarms per hour	Ref.: Rider and Hausner, *An Analysis of the Deployment of Fire-Fighting Resources in Jersey City, New Jersey*
• Consequence--if average number of alarms is 2 per hour between 2 and 4 p.m. in Jersey City, then 14% of such hours will have no alarms 27% of such hours will have 1 alarm 27% of such hours will have 2 alarms 18% of such hours will have 3 alarms 9% of such hours will have 4 alarms 5% of such hours will have 5 or more alarms	Ref.: Any table of the Poisson distribution
• Discuss what "x% of hours" means	
• 2 alarms (the average) is not even more likely to occur than 1 alarm	
10. Optional: FIRE COMPANY WORK TIMES • Discuss company work times by alarm type • Indicate that averages may be sufficient	Ref.: Chaiken, Ignall, and Walker, *Deployment Methodology for Fire Departments*

Activity	References and Notes
11. RECAP	
Go through the data analysis process	Figure DF-21
• Divide the data	
-- Find patterns on one part	
-- Verify them on the other	
• Plot and cross-tabulate	
• Construct hazard regions	
• Patterns should be	
-- useful	
-- simple	

DATA ANALYSIS

What is it? Discovering and characterizing the variations and consistencies in incidents:

- Finding patterns--in time, season, location
- Variations from the patterns are often usefully treated as random, and describable by the Poisson process

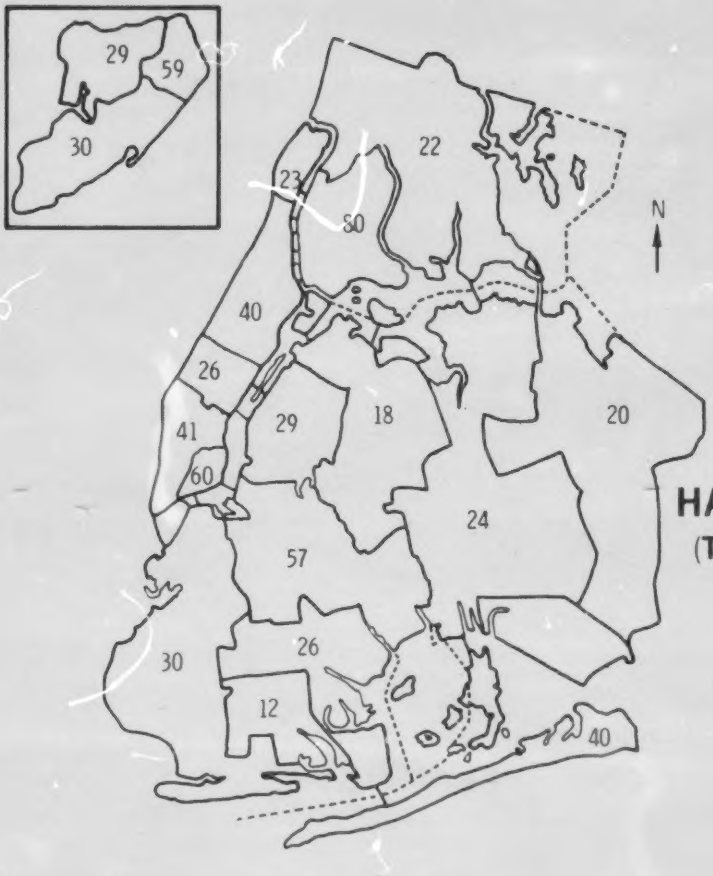
Why do it? To improve the deployment of fire-fighting resources

Fig. DF-1

COMMON ALARM PATTERNS

Pattern	Reliable	Useful For	How Much
Geographical	Relatively	Allocation	Very
Breakdown by Type	Yes	Allocation, Initial Dispatch	Some
Trend	Maybe	Allocation	Some
Season	Yes	Allocation	Slight
Day of Week	Yes	?	--
Time of Day	Yes	Initial Dispatch, Allocation	Very if alarm rate is high, slight otherwise
Weather	---	Short term allocation, for brush fires, etc.	Some

Fig. DF-2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22
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26
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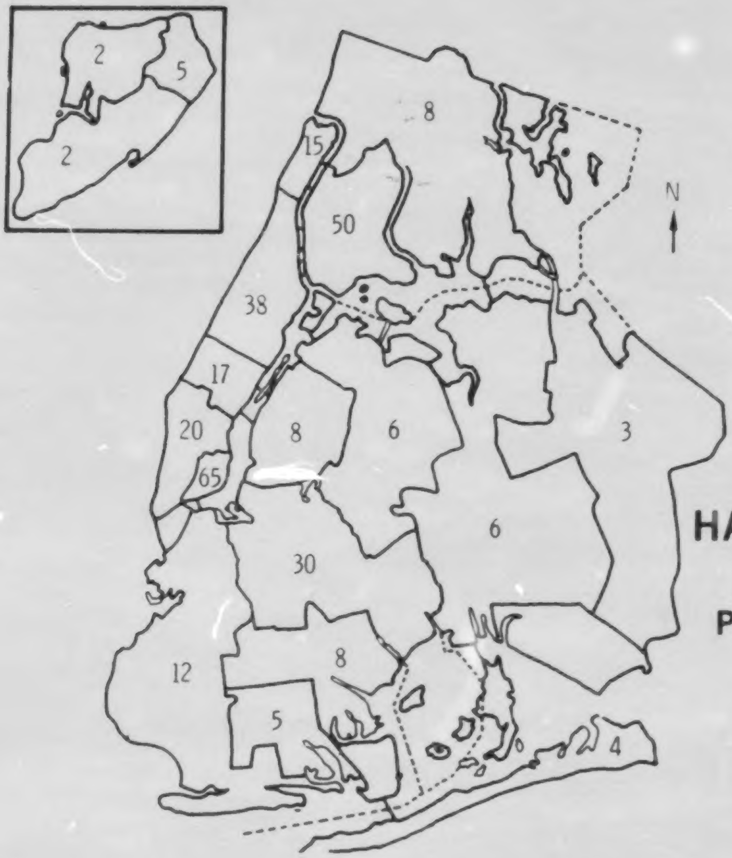
HAZARD REGION DATA
(TOTAL ALARMS PER 1000
RESIDENTS IN 1971)
NEW YORK CITY

Fig. DF-3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HAZARD REGION DATA
(HUNDREDS OF ALARMS
PER SQUARE MILE IN 1972)
NEW YORK CITY

Fig. DF-4

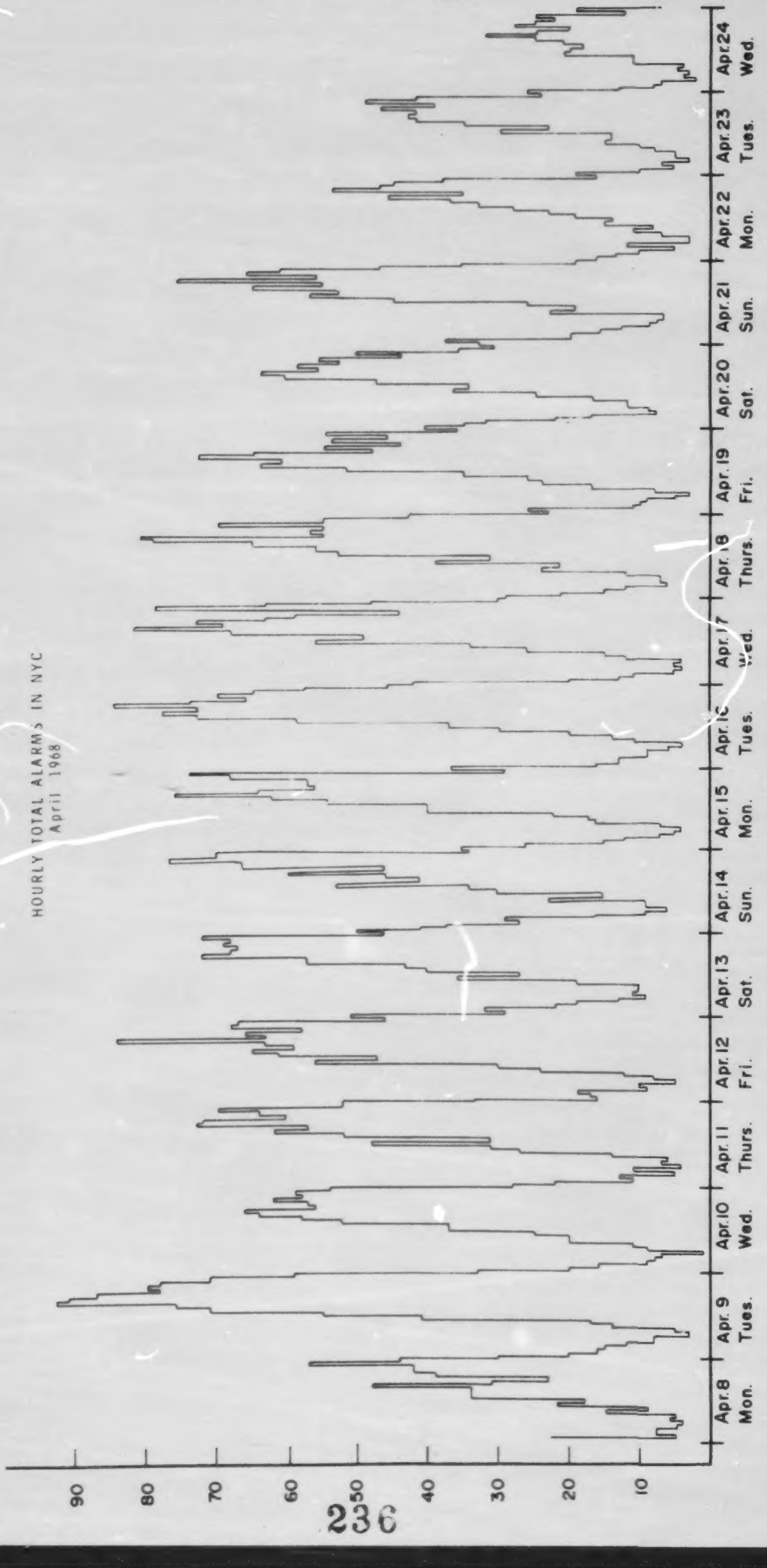

HOURLY TOTAL ALARMS IN NYC
April 1968
90
80
70
60
50
40
30
20
10
Apr. 8 Mon.
Apr. 9 Tues.
Apr. 10 Wed.
Apr. 11 Thurs.
Apr. 12 Fri.
Apr. 13 Sat.
Apr. 14 Sun.
Apr. 15 Mon.
Apr. 16 Tues.
Apr. 17 Wed.
Apr. 18 Thurs.
Apr. 19 Fri.
Apr. 20 Sat.
Apr. 21 Sun.
Apr. 22 Mon.
Apr. 23 Tues.
Apr. 24 Wed.

Fig. DF-5

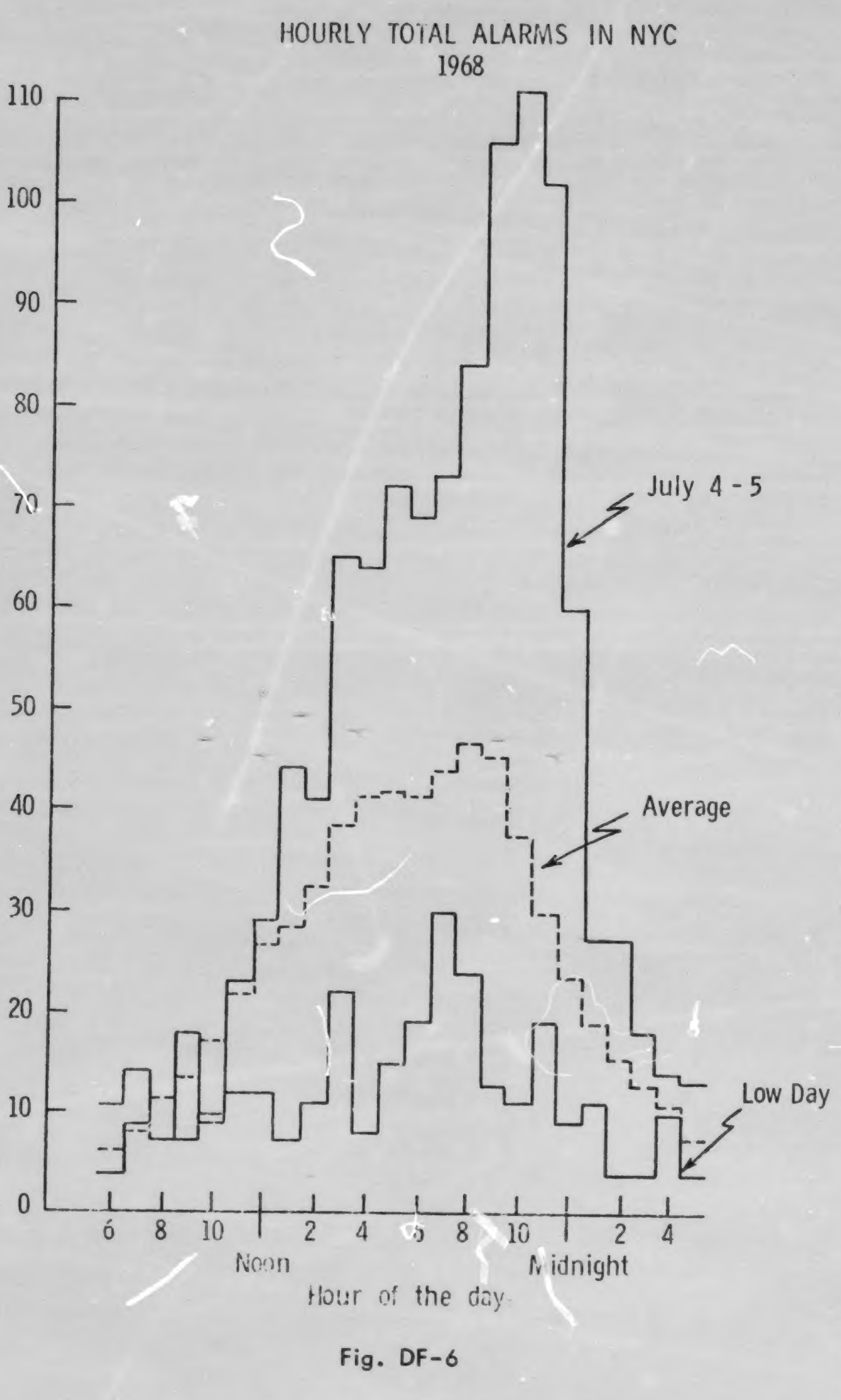

HOURLY TOTAL ALARMS IN NYC
1968
110
100
90
80
70
60
50
40
30
20
10
0
July 4 - 5
Average
Low Day
6
8
10
Noon
2
4
6
8
10
Midnight
2
4
Hour of the day

Fig. DF-6

NEW YORK CITY
WEEKLY STRUCTURAL FIRES
(INCLUDES FOOD-ON-THE-STOVE-TYPE INCIDENTS)

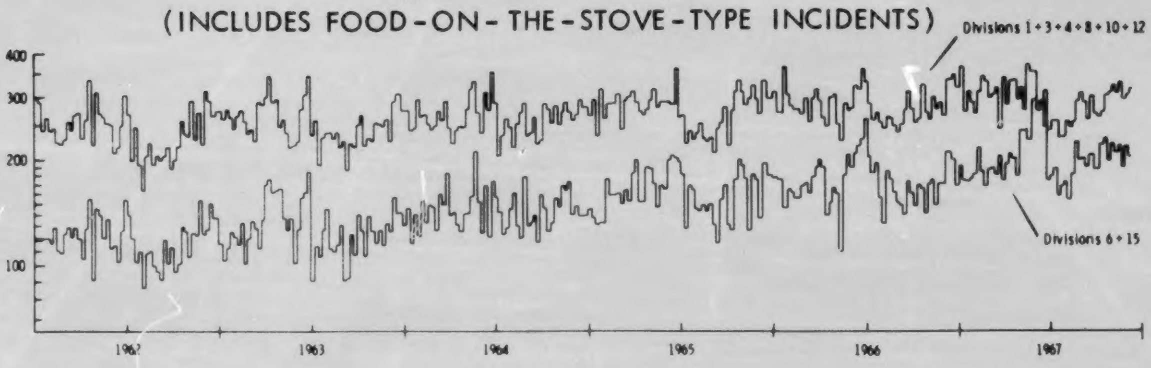


Fig. DF-7

HOURLY TOTAL ALARMS IN NYC

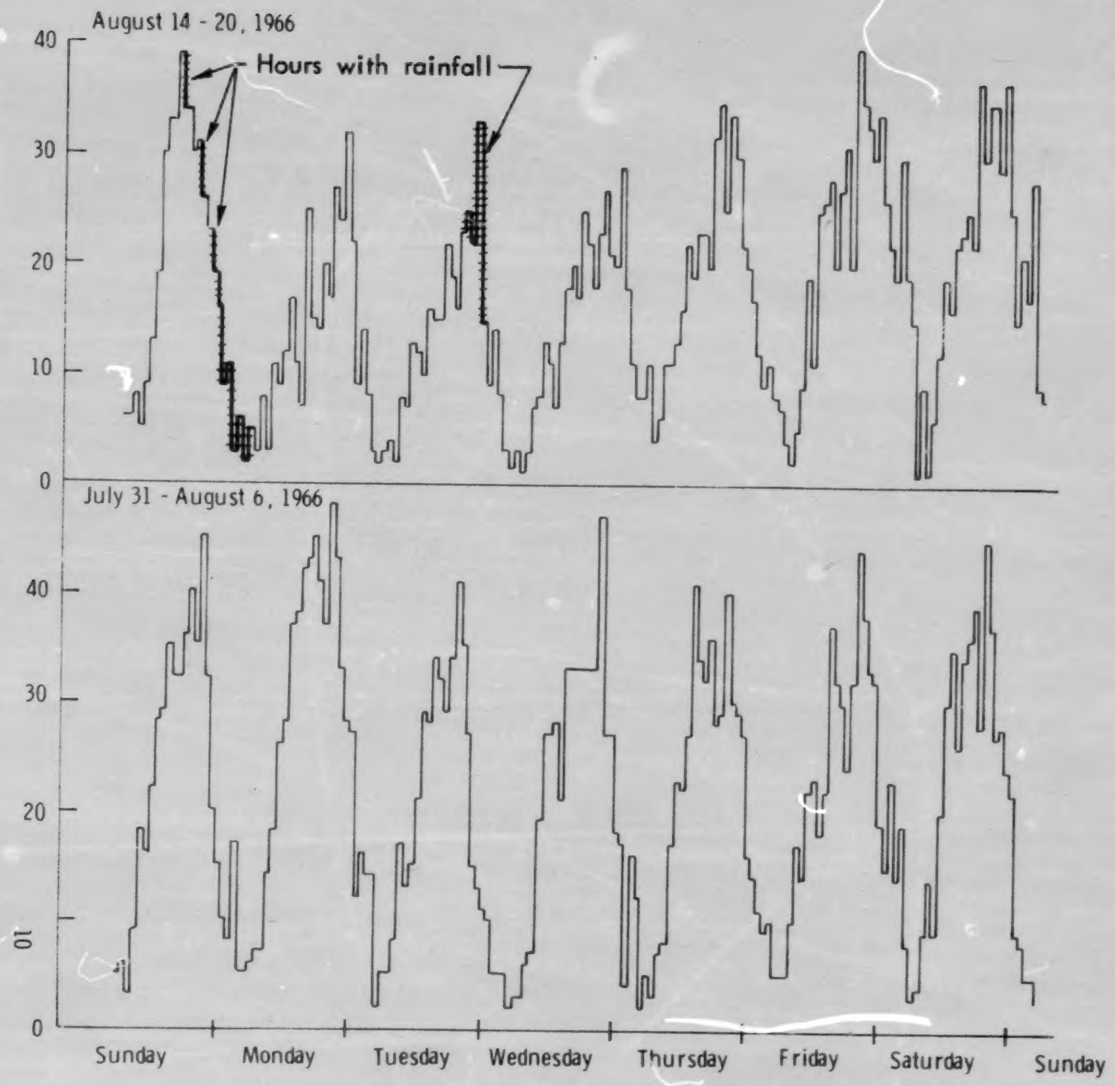


Fig. DF-8

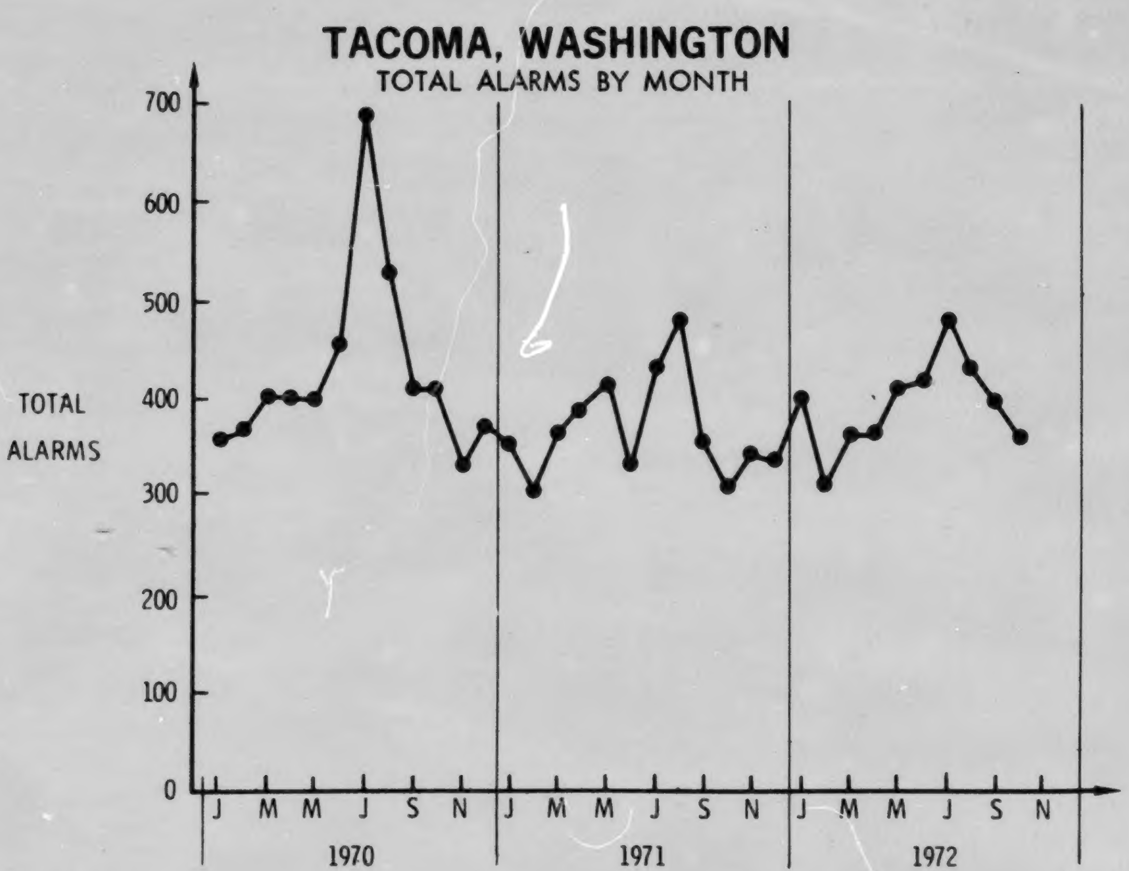

TACOMA, WASHINGTON
TOTAL ALARMS BY MONTH
TOTAL ALARMS
700
600
500
400
300
200
100
0
J
M
M
J
S
N
J
M
M
J
S
N
J
M
M
J
S
N
1970
1971
1972

Fig. DF-9

NEW YORK CITY FALSE ALARMS BY WEEK

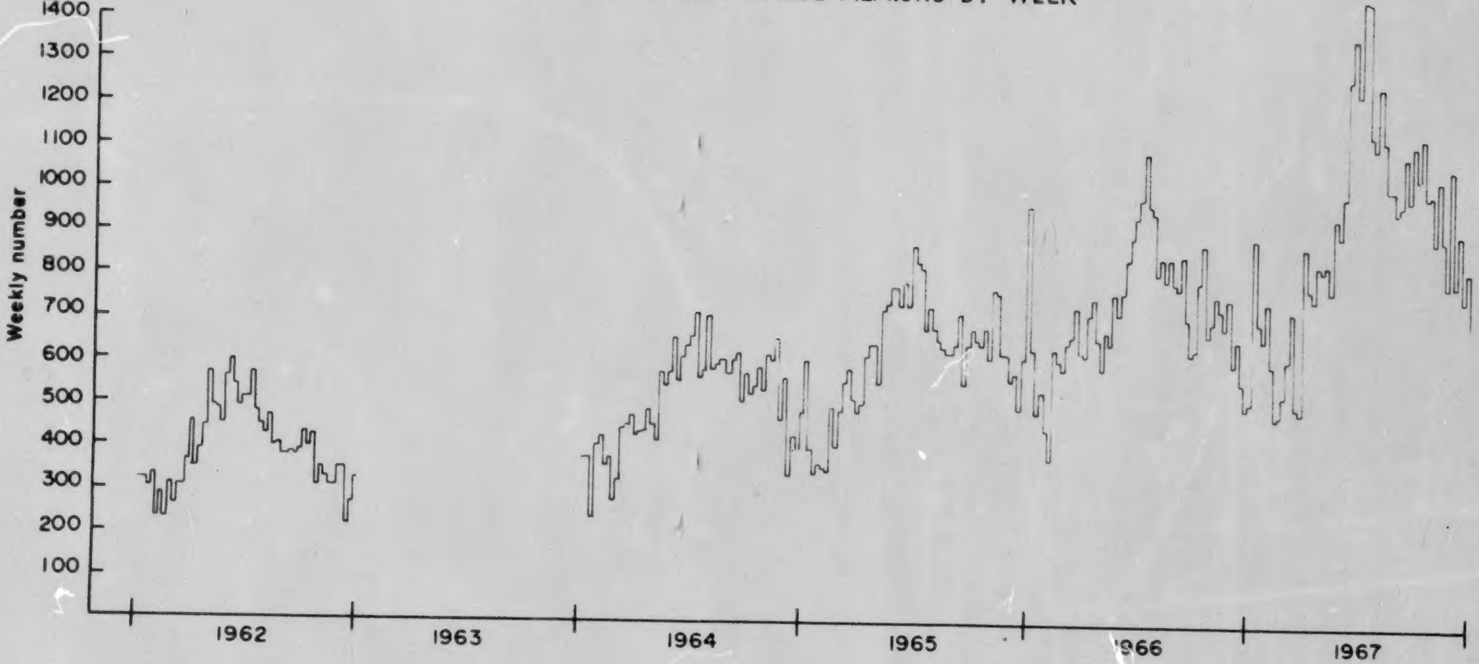


Fig. DF-10

NEW YORK CITY

RATIO OF WEEKLY FALSE ALARMS TO TREND

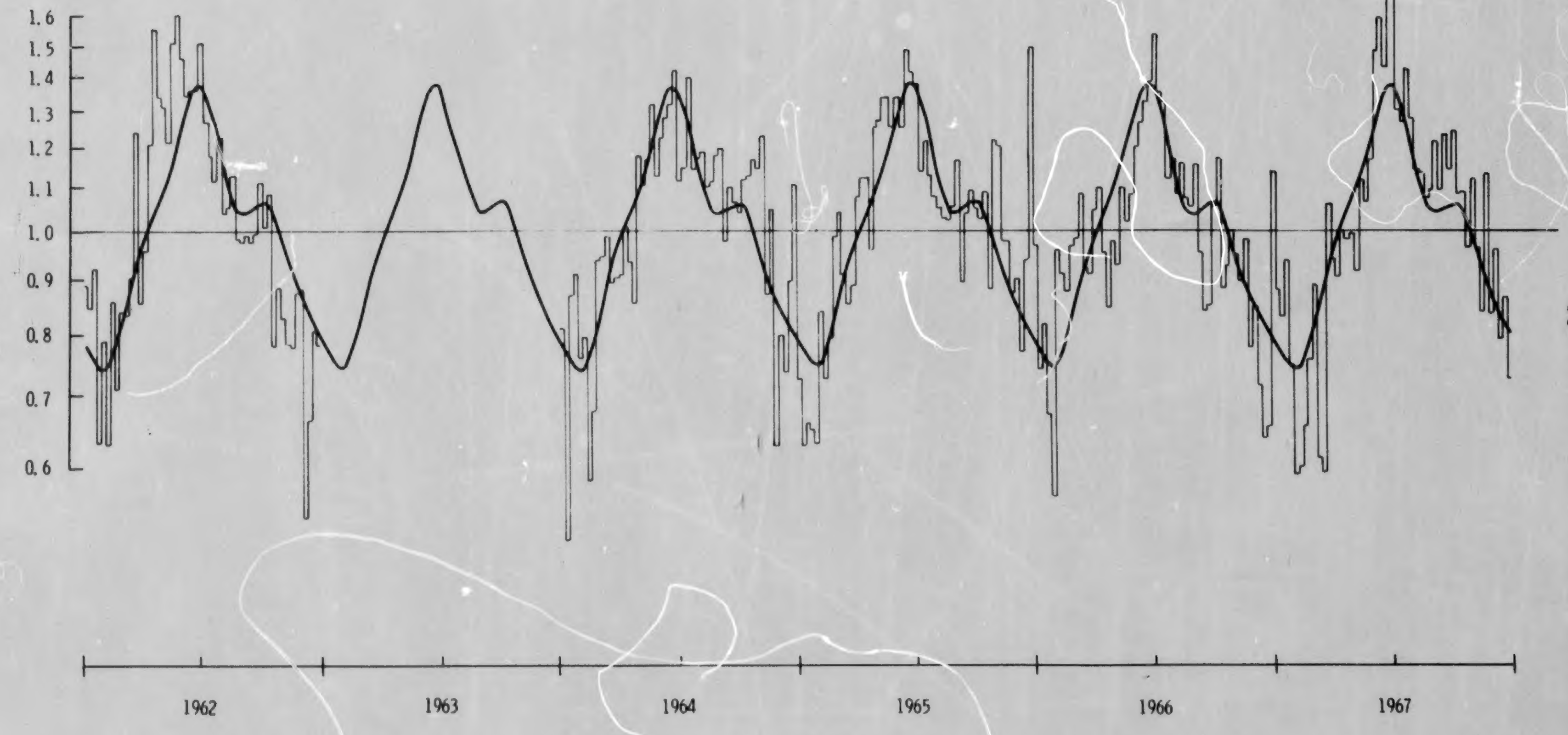


Fig. DF-11

TACOMA, WASHINGTON
(TIME OF DAY PATTERN)

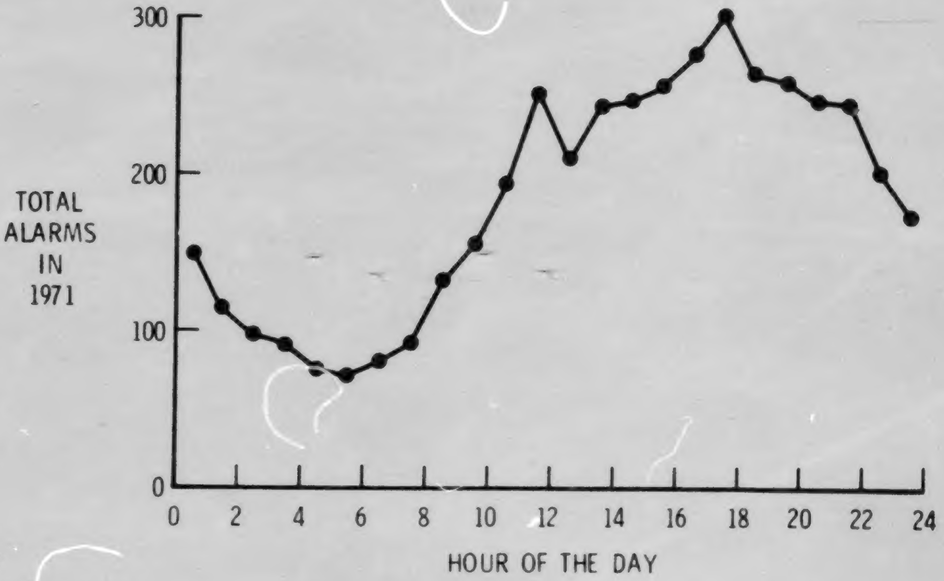


Fig. DF-12

MEASURING THE SIZE OF A PATTERN

Seasonal Pattern: Tacoma

Period		Alarms in 1971
Winter:	January, February, December	1002
Spring:	March-May	1181
Summer:	June-August	1248
Fall:	September-November	1009

High to low ratio is

1.25 = 1248/1002

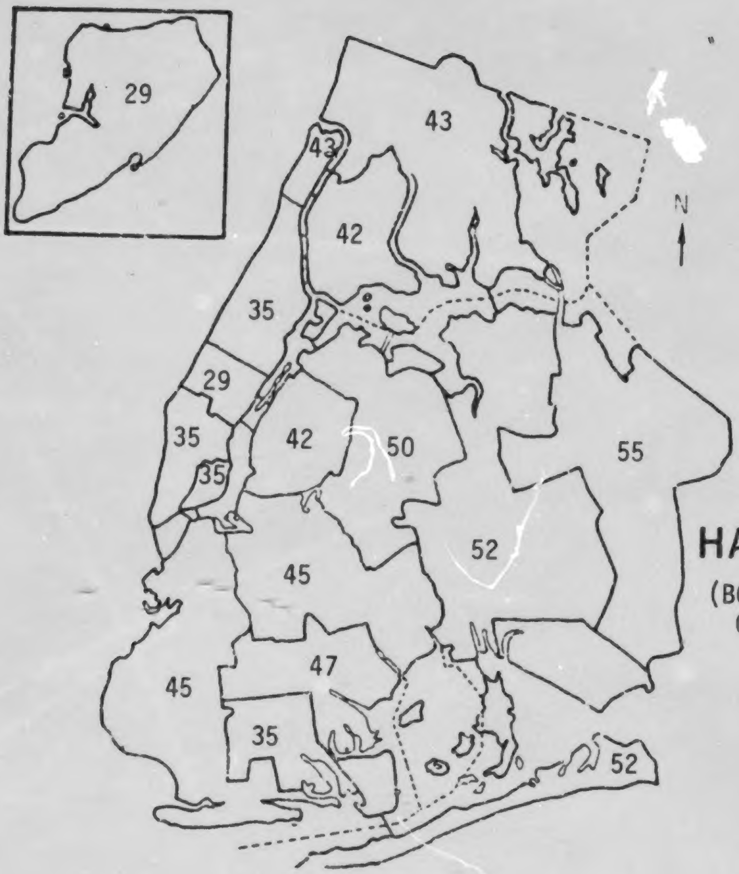
Time of Day Pattern: Tacoma

Time	Alarms in 1971
0200 - 0800	497
0800 - 1400	1195
1400 - 2000	1409
2000 - 0200	1139

High to low ratio is

2.8 = 1409/497

Fig. DF-13


29
43
43
42
35
29
35
35
42
50
55
52
45
45
47
35
52
N

NEW YORK CITY

HAZARD REGION DATA

(BOX FALSE ALARMS AS A PERCENT OF ALL BOX ALARMS IN 1968)

Fig. DF-14

STRUCTURAL FIRE PREDICTIONS FOR TWO ALARM BOXES

Bronx box number	Predicted percent structural ('67 - '69 data)	Actual 1970 Data	
		Alarms	Structural fires
2277	0.4	96	0
2209	31.8	94	25

Fig. DF-15

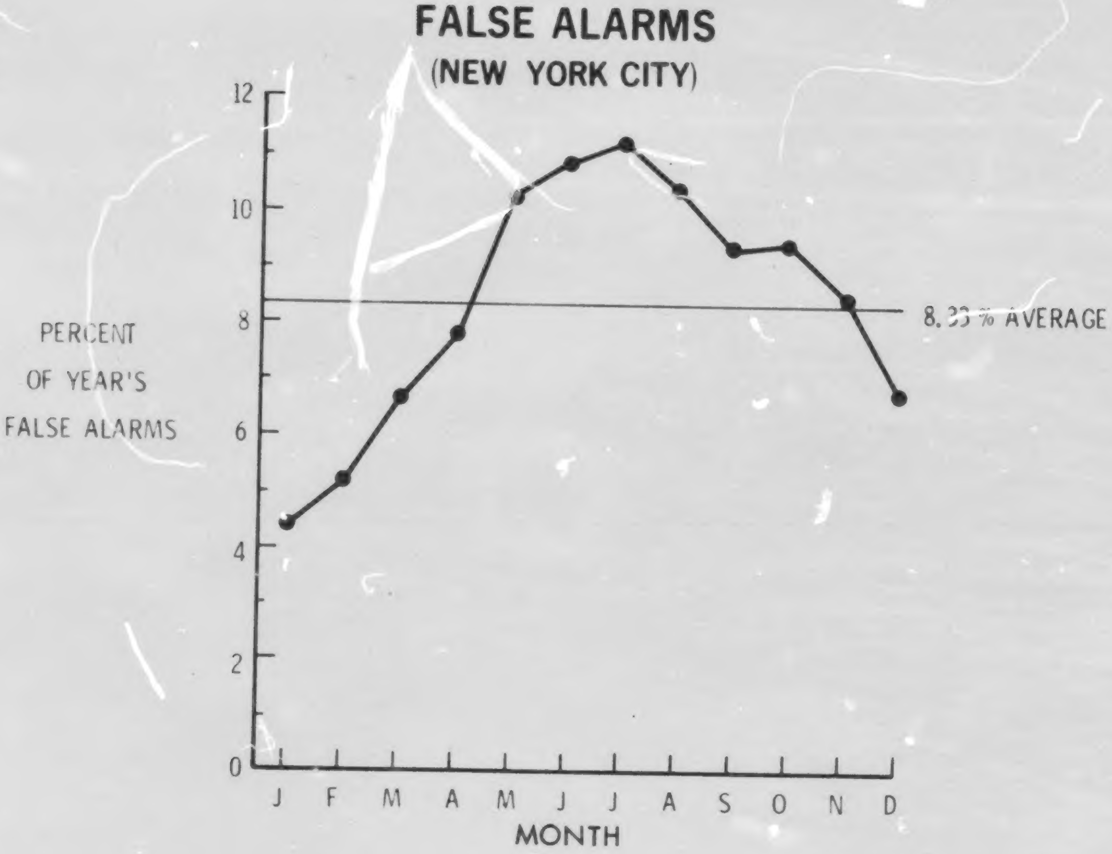

FALSE ALARMS
(NEW YORK CITY)
PERCENT OF YEAR'S FALSE ALARMS
0
2
4
6
8
10
12
8.33 % AVERAGE
J
F
M
A
M
J
J
A
S
O
N
D
MONTH

Fig. DF-16

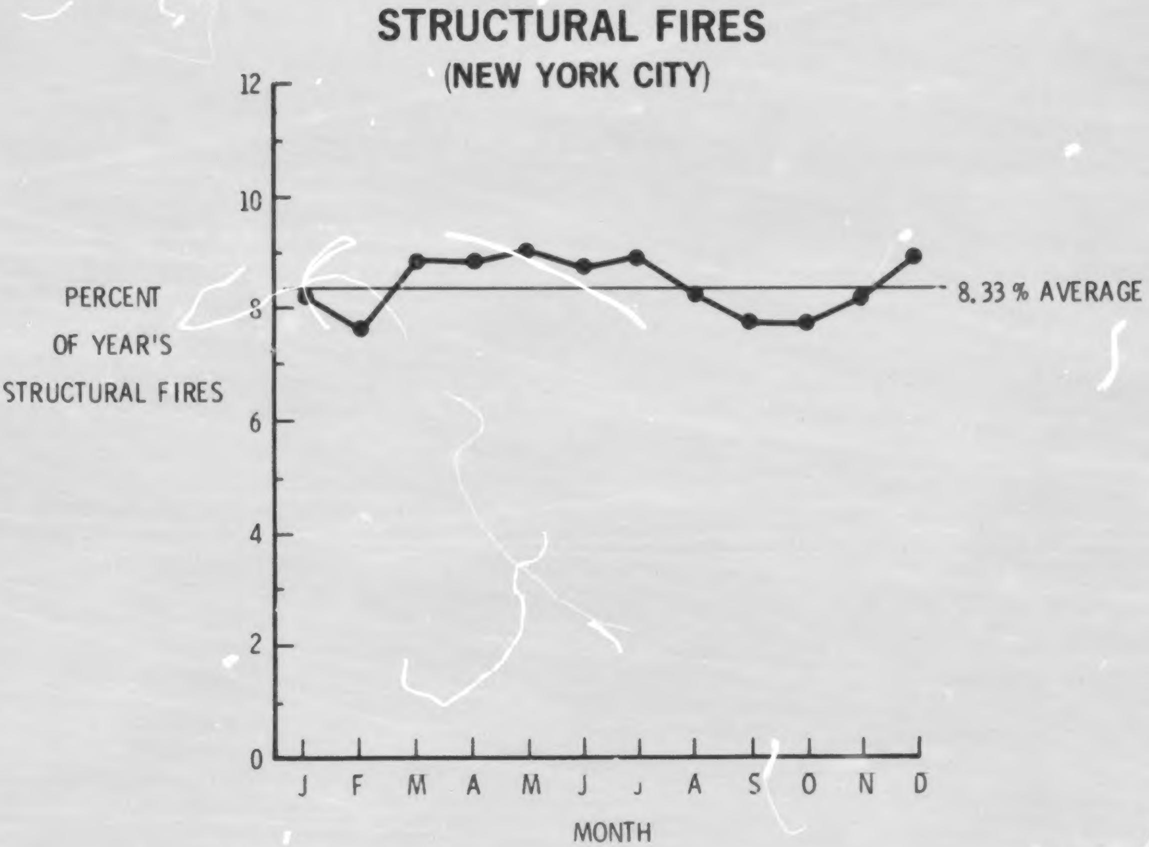

STRUCTURAL FIRES
(NEW YORK CITY)
PERCENT
OF YEAR'S
STRUCTURAL FIRES
12
10
8
6
4
2
0
8.33 % AVERAGE
J
F
M
A
M
J
J
A
S
O
N
D
MONTH

Fig. DF-17

SEASONAL AND TIME OF DAY EFFECTS IN SERIOUS FIRES AS A PROPORTION OF STRUCTURAL

(NEW YORK CITY)

		PERCENT OF ALL STRUCTURAL FIRES IN 1970 REPORTED IN THE INDICATED WAY THAT WORKED MORE THAN ONE LADDER		
		0-8	8-16	16-24
BOX	WINTER	33.8%	28.6%	25.0%
	SPRING-FALL	32.8	25.5	23.1
	SUMMER	32.6	22.0	22.2
PHONE	WINTER	20.9	15.3	11.7
	SPRING-FALL	16.0	11.9	10.3
	SUMMER	16.8	11.5	10.0

Fig. DF-18

PROPORTION OF BOX-REPORTED ALARMS THAT WERE SERIOUS FIRES, BY SEASON AND TIME OF DAY, 1964-1970 BRONX DATA

TIME OF DAY	WINTER PROPORTION	SPRING/FALL PROPORTION	SUMMER PROPORTION	OVER WHOLE YEAR PROPORTION	
0-8 a.m.	0.057	0.042	0.026	0.038	1.7
8 a.m. - 4 p.m.	0.044	0.025	0.018	0.027	1.2
4 p.m. - midnight	0.025	0.015	0.011	0.016	.7
Over Whole Day	0.031	0.021	0.016	0.022	
	1.4	1.0	.7		

Fig. DF-19

SEPARATING SEASONAL AND TIME-OF-DAY EFFECTS: SERIOUS FIRES

	Relative Seriousness: Percent of box alarms in indicated period that were serious : percent of all box alarms that were serious
0 - 8	1.7 = 3.8/2.2
8 - 16	1.2 = 2.7/2.2
16 - 24	.7 = 1.6/2.2
Winter	1.4 = 3.1/2.2
Spring, Fall	1.0 = 2.1/2.2
Summer	.7 = 1.6/2.2

	Actual Percent Serious			Percent Serious if Season and Time-of-Day Effects were Multiplicative		
	Winter	Spring, Fall	Summer	Winter	Spring, Fall	Summer
0 - 8	5.7	4.2	2.6	5.4*	3.6	2.8
8 - 16	4.4	2.5	1.8	3.8	2.5	2.0
16 - 24	2.5	1.5	1.1	2.3	1.5	1.2

*Example: 5.4% = 2.2% x 1.7[0 - 8] x 1.4[winter].

Fig. DF-20

SUMMARY

- DIVIDE THE AVAILABLE DATA IN TWO PARTS
  - Use one for finding patterns
  - Reserve the other for verifying them
- PLOT THE DATA
- MAKE CROSS-TABULATIONS
  - Time of day and season
  - Proportion serious and region
- DIVIDE CITY INTO HOMOGENEOUS REGIONS BY
  - Land use
  - Alarm data
- LOOK FOR USEFUL PATTERNS
- TRY FOR SIMPLE, ECONOMICAL MODELS
- TEST IF THE PATTERNS YOU'VE DISCOVERED ARE CONSISTENT, BY SEEING WHETHER THE RESERVED DATA FITS THEM

Fig. DF-21

LECTURE AF

ALLOCATION OF FIRE COMPANIES

Time: Approx. 60 minutes

Equipment: Computer terminal with telephone coupler (if allocation model is being demonstrated)

Objective: To introduce one approach to analyzing fire company location problems, and to explain the first step in such an analysis.

Activity	References and Notes
1. INTRODUCTION	Lecture follows Rider, A Parametric Model for the Allocation of Fire Companies
• What makes it necessary to think about changing the number and location of fire stations? -- Urban renewal -- Neighborhood changes -- Aging of firehouses -- Changes in fire department budget levels	
• Must find answers to two questions: (1) How many fire companies are needed? (2) Where should the companies be located?	
• In regard to question 1: Why not cost/benefit approach? -- Don't know relationship between dollar losses and travel times -- Requires that a monetary value be placed on human life -- Fire department is only part of the municipal budget. This approach would have to be applied to all agencies	I.e., add companies until marginal benefit would be less than marginal cost
• Practical approach	
(1) Assume a given budget level--this determines the number of fire companies	Budget level can be varied for purposes of analysis
(2) Find the best way to allocate the companies to regions of the city	Discussed later in this lecture
(3) Find specific sites for each company	Discussed in Lecture LF

Activity	References and Notes
2. ALLOCATION OBJECTIVES	
• Hypothetical examples illustrating conflict among objectives	
-- City has 2 regions of the same size with very different alarm rates	Figure AF-1. The X's on this figure do not represent the locations of anything in particular, but simply symbolize the relative numbers of incidents in the two regions
• Allocate to minimize average travel time to alarms	Overlay Figure AF-2 on Figure AF-1
-- High travel times in low incidence region -- Ignores fire hazards	Figure AF-2 shows the locations of 10 fire stations that will minimize the average travel time to incidents in the whole city
• Allocate to equalize coverage	Overlay Figure AF-3 on Figure AF-1
-- Companies in high incidence region will have high workloads -- Higher travel times to most alarms	Figure AF-3 shows an arrangement of 10 stations that makes the average response time in the "south" region the same as in the "north" region. Point out two features of this arrangement: (1) Number of stations "in" a region does not have to be an integer. The north has $5\frac{1}{2}$ stations. (2) The north has more stations than the south because on the average more companies are busy in the north
• Conclusion: Neither of these allocations is good	

Activity	References and Notes
2. ALLOCATION OBJECTIVES (continued) • Solution: Use compromise allocation -- The Parametric Allocation Model determines allocations for a range of compromises between "minimum average travel time" and "equal coverage"	
3. USEFULNESS OF PARAMETRIC ALLOCATION MODEL • Provides general picture of number of fire companies to allocate to different parts of the city • Quick and inexpensive to use • Requires very little data • Various uses -- Compare travel times and workload among regions -- Determine reallocations of current resources -- Determine regions to gain or lose companies if level of resources is to be changed	Model is operated separately for engine companies and for ladder companies. Answers provided by the model are suggestive, not precise. Use of the model can only be a first step in a study of company locations
4. DATA NEEDED FOR EACH REGION • City must be divided into hazard regions	See Lecture DF
• Travel times will be weighted in each region. Weight indicates "importance" of travel time $\text{WEIGHT} = \begin{pmatrix}\text{"EFFECTIVE"} \\ \text{ALARM} \\ \text{RATE}\end{pmatrix} \times (\text{HAZARD})$	Each factor will be described in turn. This equation is not exactly correct but gives the general idea. See item 10, below, for mathematical formulation

Activity | References and Notes

5. WHAT IS "EFFECTIVE" ALARM RATE?

- Each type of alarm is counted in proportion to its seriousness
- If all alarms are considered of equal seriousness, then the effective alarm rate is the same as total alarm rate

This is unlikely to be a desirable choice, but may be necessary if no better data are available

- Can count only structural fires, or only fires that required more than a certain amount of work to extinguish (e.g., one company-hour)
- Can weight each type of alarm by the number of company-hours needed to extinguish it. Then

$$\begin{pmatrix}\text{"EFFECTIVE"}\\ \text{ALARM RATE}\end{pmatrix} = \begin{pmatrix}\text{ALARM}\\ \text{RATE}\end{pmatrix} \times \begin{pmatrix}\text{COMPANY-}\\ \text{HOURS}\end{pmatrix}$$

$$= \begin{pmatrix}\text{AVERAGE NUMBER OF}\\ \text{COMPANIES BUSY}\end{pmatrix}$$

See Lecture RF

6. WHAT IS THE HAZARD FACTOR?

- Subjective measure of the relative danger of a fire (potential for loss of life or property if a fire does occur)
- Suppose the most hazardous region is given a hazard rating of 1.0. Then a region with hazard rating 0.9 is less hazardous to the extent that travel times could be about 10 percent higher in this region, and the department would be willing to say equal quality fire protection is being provided in the two regions
- This is a subjective management input. When using the model, can try several different ways of defining hazards and see what the consequences are

Activity	References and Notes
7. CITYWIDE DATA NEEDED	
• "Constant" and "power" in the relationship between travel time and number of companies: $\left(\begin{array}{c}\text{AVERAGE TRAVEL}\\ \text{TIME in a region}\end{array}\right) = (\text{CONSTANT}) \times \left(\frac{\text{AREA}}{\begin{array}{c}\text{AV. NUMBER}\\ \text{COMPANIES AVAIL.}\end{array}}\right)^{(\text{POWER})}$	This combines "rules of thumb" numbered 2 and 3 in Lecture RF. See also Kolesar, A Model for Predicting Average Fire Company Travel Times
8. DECISION VARIABLES	
• Total number of companies to be allocated to the city	May be changed in different runs of the computer program
• Tradeoff parameter beta (β). This accomplishes the compromise between "minimum average travel time" and "equal coverage"	
-- For β = 1, program shows an allocation that minimizes the average weighted travel time	The weight is discussed above, in item 4
-- For large β (50 or more), program shows an allocation that will make the weighted response time equal in all regions	
-- [For small β, workload is equalized]	
• How does the department choose its desired value of β?	
-- Try different values between 1 and 50. See what happens	This will be illustrated in the demonstration
-- β = 3 was found to be "good" in New York City	I.e., the administrators liked the resulting allocations
-- It often happens that all values of β indicate that certain hazard regions should lose companies as compared to the present arrangement, and others should gain companies. Such a conclusion is "robust," because any "reasonable" value of β leads to a qualitatively similar conclusion	

Activity | References and Notes

9. OUTPUT

- The number of companies to be located in each hazard region
- The average travel time in each region, given the number of companies allocated
- Citywide averages

10. MATHEMATICAL FORMULATION (Optional)

M = total number of companies to be allocated in the city

n_i = number of companies allocated in region i

λ_i = effective alarm rate in region i

h_i = hazard rating for region i

$\tau_i(n_i)$ = average travel time in region i, given n_i companies there

$$= c\left(\frac{A_i}{n_i - b_i}\right)^{\alpha}$$

c and α are the travel-time "constant" and "power"

A_i = area of region i

b_i = average number of companies busy in region i

Optimization problem:

- Minimize $\sum_i \lambda_i (h_i \tau_i (n_i))^{\beta}$

  subject to $\sum_i n_i = M$

- β is the tradeoff parameter

Activity	References and Notes
11. LEAD-IN TO DEMONSTRATION	
• Jersey City will be chosen as an example	Ref.: Rider and Hausner, *An Analysis of the Deployment of Fire-Fighting Resources in Jersey City, New Jersey*
• Display map of city	Figure AF-4
• Discuss	
-- definition of demand regions	(Same as hazard regions) Figures AF-5, AF-6, AF-7
-- objective was to plan in terms of alarm rates to be expected in the future	
12. DEMONSTRATION	Lecturer operates program on-line *or* prepares printout in advance *or* uses suitable tables from Rider and Hausner report cited above. Table numbers that follow refer to this report Reference for operating the program: Rider, *A Parametric Model for the Allocation of Fire Companies: User's Manual*

Activity	References and Notes
12. DEMONSTRATION (continued)	
• Describe "base case" situation	Model 1. Interpret printout headings, if using printout
-- Discuss response times .. Differences between regions .. Citywide average, noting that it is weighted by regional alarm rates .. Average and percentage busy indicate relative workloads	Table 4-1
• Derive allocations for different values of the tradeoff parameter -- Interpret fractional allocations	Model 3. Tables 4-2, 4-3. WARNING: The "parameter" in this program is $1/\beta$
-- Point out that parameter = .25 produces good approximation of current allocation	This corresponds to $\beta = 4$
• Find reallocation for parameter = .25 based on 1983 alarm rates	Tables 4-4, 4-5
• Allocations for different numbers of total companies	Tables 4-6, 4-7
• [optional] Comparison of different specific allocations with the current situation	This is Model 2

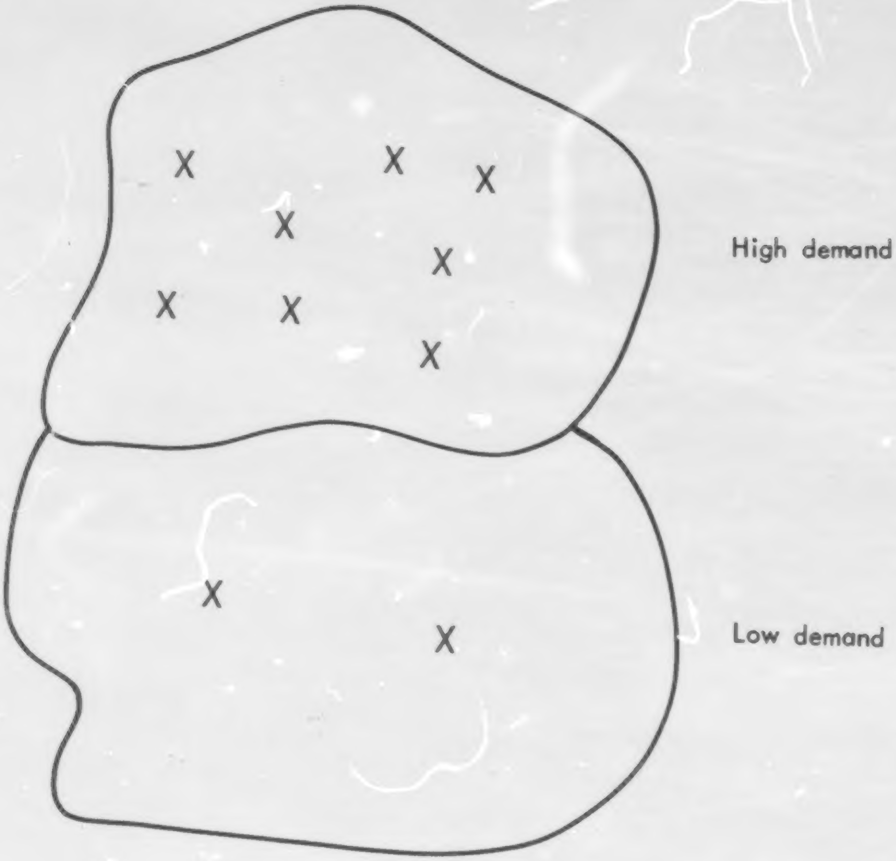

High demand
Low demand

Fig. AF-1

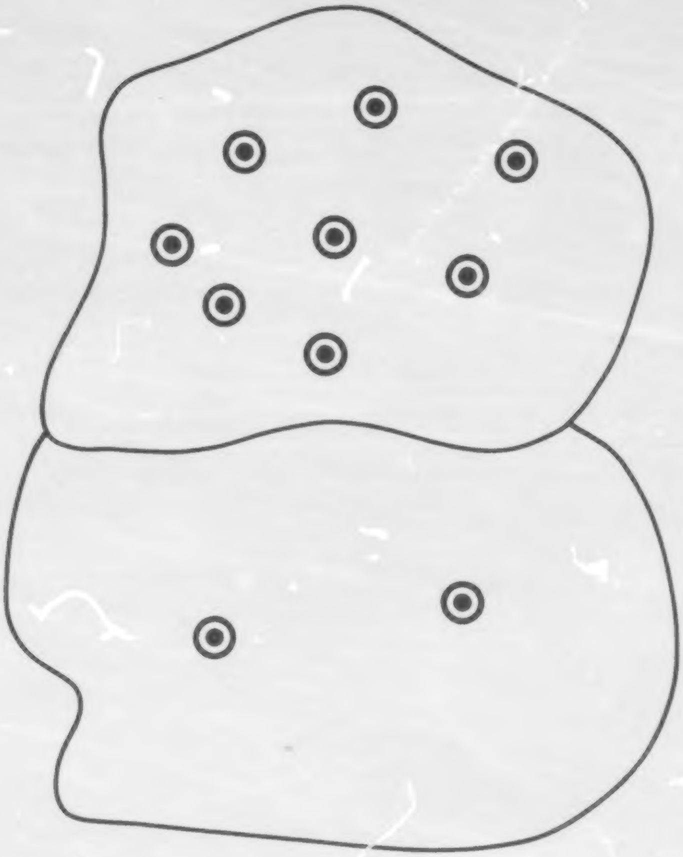


Fig. AF-2 — Minimum total response time to all fires

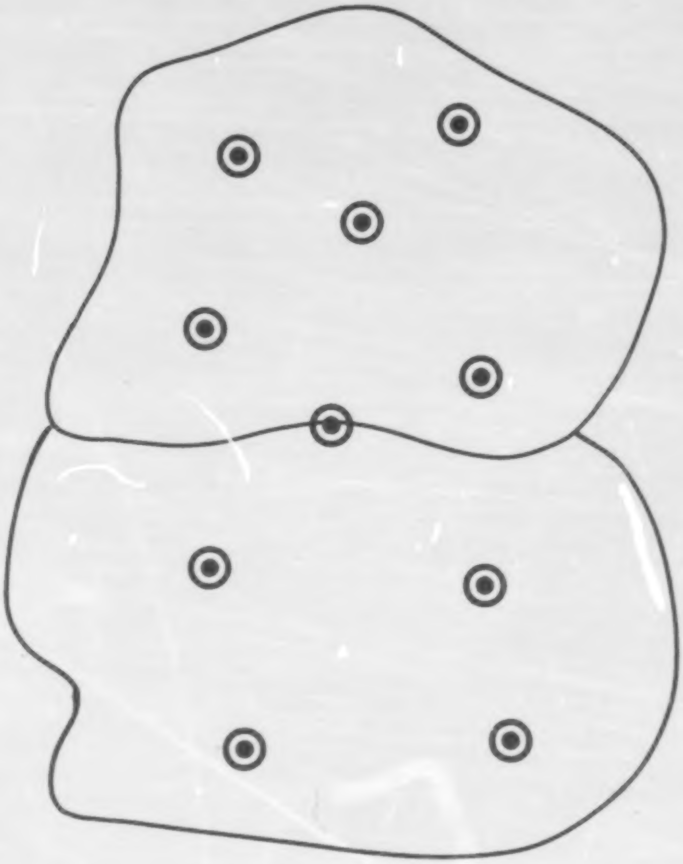


Fig. AF-3 — Equal coverage for both areas

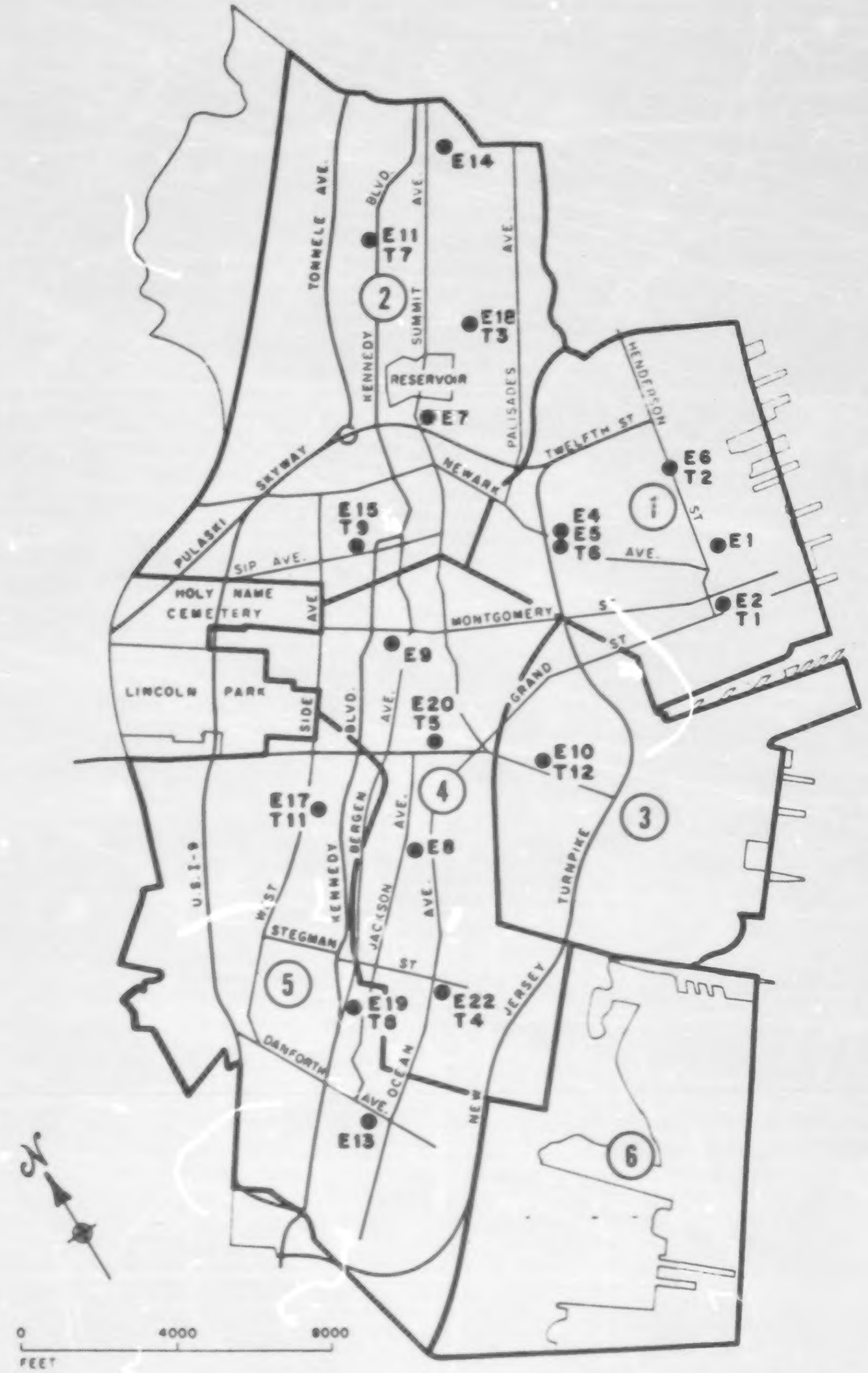

E14
TONNELE AVE.
BLVD.
AVE.
E11
T7
2
KENNEDY
SUMMIT
AVE.
E18
T3
RESERVOIR
PALISADES
HENDERSON
E7
TWELFTH ST
SKYWAY
NEWARK
E6
T2
1
ST
PULASKI
E15
T9
E4
E5
T6
AVE.
E1
SIP AVE.
HOLY NAME
CEMETERY
AVE
MONTGOMERY
ST
E2
T1
E9
ST
GRAND
LINCOLN PARK
SIDE
BLVD.
AVE.
E20
T5
E10
T12
E17
T11
BERGEN
AVE.
4
3
U.S. 1-9
WEST
KENNEDY
E8
JACKSON
AVE.
TURNPIKE
STEGMAN
ST
5
E19
T8
E22
T4
JERSEY
OCEAN
DANFORTH
AVE.
NEW
E13
6
N
0
4000
8000
FEET

Fig. AF-4 — Map of demand regions and fire company locations

Demand Region	Name	Area (Sq.Miles)	Population 1970	Population per Sq.Mile (Thousands)	Housing Units	1-2 Family Dwelling		Vacant Units		Basic Characteristics
						Number	%	Number	%	
1	Down-town	1.52	34,876	22.9	12,512	1,830	14.6	936	7.5	Secondary downtown area, high-rise multiple dwellings, waterfront
2	Hudson Heights	2.82	82,060	29.1	30,447	11,965	39.3	1,050	3.4	Primary downtown area, semidense residential
3	Lafayette Liberty Harbor	0.85	11,721	13.8	3,857	954	24.7	245	6.4	Mainly industrial, some residences
4	Bergen	1.98	76,019	38.4	26,589	12,651	47.6	1,390	5.2	Dense residential area, small businesses
5	West-side Greenville	2.59	54,937	21.2	18,339	10,806	58.9	474	2.3	Less dense residential, some industry
City-wide		9.76	259,613	26.6	91,744	38,206	41.6	4,095	4.5	

Fig. AF-5 — Demand region demography

Demand Region	Number		Alarms/Sq.Mile		Alarms/Capita		Fires in Residences		
	Total	Structural	Total	Structural	Total	Structural	Number	% of All Structural	Per Capita
1	3,308	395	2,176	260	.0949	.0113	305	74.6	.0088
2	2,459	390	872	138	.0300	.0048	326	81.5	.0040
3	838	113	986	133	.0715	.0096	110	79.1	.0094
4	3,366	840	1,700	424	.0442	.0111	698	89.0	.0092
5	1,599	279	617	108	.0291	.0051	244	84.1	.0044
City-wide[a]	11,570	2,017	1,185	207	.0446	.0078	1,683	83.2	.0065

[a] Excluding Region 6.

Fig. AF-6 — Demand region alarm incidence

Region	Area Sq.Miles	Alarms per Hour 4 p.m. to Midnight			
		All	False	Nonserious Structural	Serious Structural
1	1.52	.722	.403	.040	.015
2	2.82	.444	.137	.047	.009
3	0.85	.202	.083	.027	.003
4	1.98	.630	.290	.094	.013
5	2.59	.330	.127	.039	.007

Fig. AF-7 — 1972-1973 alarm rates

LECTURE LF

LOCATING FIRE STATIONS

Time: Approx. 70 minutes including demonstration of program

Objective: To discuss the general problem of locating fire stations, and to compare two specific approaches to the problem.

Equipment: Portable terminal with acoustic coupler for demonstration.

Activity	References and Notes
1. INTRODUCTION • Topic is evaluation of current fire station sites, and planning which ones to close and/or where to put new ones	Lecture follows Chapter IV of Chaiken, Ignall, and Walker, *Deployment Methodology for Fire Departments*
• Discussion may be followed by demonstration	Demonstration is optional. Alternatively, copies of previously run output can be discussed. This will cut time of lecture to 50 minutes
• NYCRI treats this question in two stages: (a) Obtain ideas and insights from the allocation model (b) Use a descriptive model to evaluate specific configurations	Refer to lecture AF. NYCRI = New York City-Rand Institute
• Other approaches perform analyses in one stage	Lecture covers both

Activity	References and Notes
2. GENERAL APPROACHES	Expanding on Lecture AF
• Minimize sum of fire department costs and expected fire losses (including fatalities). A worthy objective; some studies have been done along these lines in Great Britain. Problem: No generally useful way has been found to estimate fire losses from response times	Ref.: Hogg, "Station Siting in Peterborough and Market Deeping"
• Minimum average response time. May not be a good idea, as tends to indicate greatest need for stations in high-alarm areas while ignoring low-fire areas. When choosing among otherwise equally satisfactory configurations, may be useful	
• Coverage. Each potential fire site should be within reasonable distance (or time) of a fire station. Easy to apply, but too simplistic and based on subjective judgments	ISO Grading Schedule

Activity	References and Notes
3. MEASURES FOR EVALUATING ALTERNATIVES	
• Use surrogate measures for fire loss. Give decisionmaker information on how a given configuration will perform using several measures of fire protection	Refer to Lecture OF
-- One configuration will probably not dominate another configuration on all measures	
-- Administrators must subjectively balance the measures; they will also add judgments concerning hazards and political constraints	
• Primary considerations:	
-- Travel times. Make sure that each potential fire site is within a reasonable time from a firehouse	
-- Hazards. Want to single out some potential fires as more important than others for achieving rapid response	
-- Average regional travel times. Useful for evaluating relative fire protection in different areas of a city	Can use unweighted or weighted averages. Weighting can be by total alarms or structural alarms
-- Fire company workload. May want to balance workload over companies. Most important when workload is high	

Activity	References and Notes
4. GENERAL DATA REQUIREMENTS • Geographic division -- Divide city into small subareas, as small as the area covered by a single alarm box (real or phantom), perhaps four or five times this size -- Assume all demand for fire service in the subarea arises at one point. Estimates of travel times to any point in the subarea will be the same as to that point -- Find historical (or expected future) fire incidence in each subarea • Identify points at which construction of a firehouse is feasible. Failure to do this will lead to consideration of options that are infeasible and impractical • Identify those subareas having special hazards -- Analysis will pay special attention to these subareas • Must have some method for estimating travel time from any firehouse (existing or proposed) to any subarea • Obtain estimates of capital construction costs; and current costs of depreciation, operation, and maintenance of existing stations	Common to most approaches to firehouse siting

Activity	References and Notes
5. ESTIMATING TRAVEL TIMES	
• Method 1. Developed by Public Technology, Inc. (PTI)	
-- Describe street network of city in computer-readable form. Street intersections are identified as nodes in the network, streets are represented as connecting links between nodes. Not necessary to consider all streets; main arterials are adequate	Figure LF-1
-- Estimate average travel speed on each link. This may be done from experienced guesses, traffic surveys, experimental trips by fire companies, or from previously collected response-time data	
-- Estimate time to travel over each link using speed and distance	
-- Subareas are called fire demand zones; the point representing all the properties in a fire demand zone is called a focal point	
-- Every potential or existing firehouse and every focal point is referenced to a node of the street network	
-- The travel time from a firehouse to a focal point is estimated by finding the set of connecting arcs that form the minimum time path	

Activity	References and Notes
5. ESTIMATING TRAVEL TIMES (continued)	
• Method 2. Developed by NYCRI	
-- Run a "travel-time experiment" showing origin and destination for each response by fire companies, odometer distance traveled, and the time required for the response Data can be collected in the units, or at the dispatch center if units radio in when departing and arriving	Figure LF-2. Ref.: Hausner, Determining the Travel Characteristics of Emergency Service Vehicles
-- Fit a smooth curve to data showing actual travel time versus distance	
(a) In some cities, straight line with positive intercept provides best fit (b) In most, a blend between straight line and a square-root curve is best	Ref.: Kolesar and Walker, Measuring the Travel Characteristics of New York City's Fire Companies
(c) Curve may vary in different parts of the city and at different times of day. But experience has shown that neither effect is large, and that approximately the same curve can be used for any city at all times of day	Figures LF-3, LF-4, LF-5
-- Determine x-y coordinates of existing and potential fire station sites on a grid map of the city. Determine x-y coordinates for the subareas in which incidence will be estimated	
-- Estimate distance from stations to subareas in some way, e.g., as sum of x and y distance traveled (right-angle distance) or a modification of straight-line (Euclidean) distance	Alternatively, can fit curve to data showing actual travel time vs. estimated distance, and use this curve. See Hendrick et al., An Analysis of the Deployment of Fire-Fighting Resources in Denver, Colorado
-- Parameters of fit curve are used to estimate travel time between any two points, using estimated distance	

Activity | References and Notes

5. ESTIMATING TRAVEL TIMES (continued)

- Relative advantages of Method 1
  - -- If road network has already been developed (by traffic department, for example), this is fastest way to proceed
  - -- Road network, when developed, may be useful to other city agencies
  - -- Barriers to travel (hills, railroad tracks, rivers, airports) are automatically taken into account
  - -- Effects of changes in structure of road network can be analyzed in advance (new interstate highway, new bridge, closing of existing bridge)
  - -- Irregularly shaped areas (peninsulas, or cities with holes in them, for example) are automatically handled accurately
  - -- Fire officials may feel more comfortable with a method that actually imitates the path followed by fire companies, whether or not method is actually accurate
- Relative advantages of Method 2
  - -- Elaborate data base and computer program not needed; lower cost for analysis
  - -- If road network has not already been developed, this method is significantly faster
  - -- If travel times have already been collected (e.g., by UFIRS), this method is very fast

    UFIRS = Uniform Fire Incident Reporting System, developed by the National Fire Protection Association
  - -- Parameters for fit curve have been so close to the same values for many cities that it may be possible to proceed without collecting any travel-time data
  - -- Method has been validated against actual travel-time data and has been found accurate enough for site selection
  - -- In case of irregularly shaped areas, ad hoc adjustments to method are easily accomplished
- The travel-time estimates produced by Methods 1 and 2 have never been directly compared

Activity

6. GENERATING POSSIBLE SITE CONFIGURATIONS TO EVALUATE

- Method 1. Developed by PTI
  - -- Still in developmental stage; requires PTI's assistance
  - -- A maximum travel time is specified for each focal point
  - -- A set of existing and potential firehouse sites is specified
  - -- A computer program determines whether any collection of potential station locations can meet the travel-time requirements. If so, it prints out a solution that requires the smallest possible number of sites
- Advantages of Method 1
  - -- Procedure is very well defined. Documentation provides step-by-step guide to the tasks that must be carried out to use the program and provides forms for collecting and organizing required data
  - -- Method is potentially very powerful. If maximum travel times can be determined, can generate, among the large number of possible configurations, the one that meets all requirements with the fewest number of fire companies

References and Notes

Ref.: "PTI Fire Station Location Package"

Activity	References and Notes
6. GENERATING POSSIBLE SITE CONFIGURATIONS TO EVALUATE (continued)	
• Difficulties with Method 1 -- No accepted standards for travel-time constraints -- Once fire officials agree on a set of requirements, the resulting number of stations needed may exceed any reasonably foreseeable budget. Constraints must then be relaxed -- Travel-time requirements corresponding to existing number of stations may be hard to determine -- PTI program may fail to operate, leading to no solution -- Recommended station configuration may involve moving many stations, while another equally acceptable configuration (not known) involves moving fewer stations. Other acceptable solutions (also not known) may be preferable in regard to average travel time or other characteristics	
• *Method 1M*. Modification developed by University of Colorado -- Same approach as PTI's -- Computer program finds a configuration that meets the requirements and has the minimal number of stations. This configuration includes the largest possible number of existing station sites	Hendrick et al., *An Analysis of the Deployment of Fire-Fighting Resources in Denver, Colorado*

Activity	References and Notes
6. GENERATING POSSIBLE SITE CONFIGURATIONS TO EVALUATE (continued)	
• Method 2. Used by NYCRI	
-- Use allocation model to determine demand regions needing more or fewer stations	Discussed in Lecture AF
-- From a map of the city showing existing and potential sites, select several possible configurations that approximately match desired allocations by region	Requires discussion with policymakers. No computer program is involved
-- Use siting model (to be described next) to compare the trial configurations. Develop improved trial configurations by looking at the results for others	
• Virtues and difficulties with Method 2	
-- Easy to use; fast to implement	
-- Process of choosing configurations requires judgment and "map sense"	
-- May overlook good configurations	

Activity	References and Notes
7. EVALUATING TRIAL CONFIGURATIONS	
NYCRI has a "Firehouse Site Evaluation Model" that calculates a set of descriptive measures for any pair of configurations. Other researchers have similar computer programs, differing only in details	Ref.: Dormont, Hausner, and Walker, Firehouse Site Evaluation Model: Description and User's Manual
(a) Calculations are based on a number of assumptions	
• All units are always available in their firehouses to respond to an incoming alarm (reasonable assumption for most cities)	
• The closest units are always dispatched to an alarm	
• Calculations are performed separately for each type of fire-fighting equipment	
• Travel distances are estimated by right-angle or "modified" Euclidean distance	If D_E is Euclidean distance, k x D_E is "modified" Euclidean
• Travel times are estimated from empirically determined curve	Discussed above, item 5

Activity	References and Notes
7. EVALUATING TRIAL CONFIGURATIONS (continued)	
(b) Performance measures	
• For each demand region, citywide, identified target hazards, and/or region affected by change: average travel time and average travel distance	"Demand region" is the same as "hazard region"
-- weighted by expected incidence and unweighted (each subarea given equal weight)	"Incidence" can be all alarms or structural fires
-- first-due, second-due, third-due, etc.	
• Frequency distribution of travel times for each demand region and citywide	
• For each company's first-due response area: average travel time, maximum travel time (to farthest subarea), workload (incidents/year), and a list of the subareas (alarm boxes) that constitute the response area (this information is also available for second-due areas, etc.)	
• Travel time and travel distance to each subarea (alarm box) identified as a target hazard	
• A list of the subareas whose first-due travel times are improved by the change, and those whose first-due travel times are worse, plus the alarm incidence at each group of boxes and average travel times within each group, both before and after the change	

Activity	References and Notes
8. DATA REQUIREMENTS FOR FIREHOUSE SITE EVALUATION MODEL (Aside from general data requirements described earlier)	
• List of subareas containing target hazards -- Purpose: to have program specifically indicate the travel times to these subareas -- Effect of changes in travel times to these subareas is important	
• (x-y) coordinates for every subarea, existing station, and potential station	
• A list of subareas included in each company's current response areas	Basically, the current running cards
• Parameters of the curve relating travel time to travel distance	Hausner, Determining the Travel Characteristics of Emergency Service Vehicles

Activity	References and Notes
9 DEMONSTRATION OF MODEL • Be sure to make some change in station locations before running program. Otherwise the "old" and "new" columns will be the same, and there will be no "affected region" • Preferably, the changes should not be elaborate; the point is not to show what the biggest possible performance change would be in one city. Suitable tests are:	Follows Hausner and Walker, An Analysis of the Deployment of Fire-Fighting Resources in Trenton, New Jersey. Section numbers below refer to this report
-- Trenton engines M E3-8431 M E1-2232 M E8-2432 O C=(E)	Section 4.2.2
-- Trenton ladders M L1-2232 O C=(L) or M L1-2432 O C=(L)	Section 4.2.1 provides an analysis of these two options To test other changes, you need a map showing Trenton's alarm boxes

Activity

9. DEMONSTRATION OF MODEL (continued)

- Command language

  (E can be replaced by L)

  M Enn-mmmm

  Move engine nn to subarea or box mmmm [e.g., M E10-2104]

  D Enn

  Delete engine nn [e.g., A E12-3510]

  A E-mmmm

  Add an engine at box mmmm

  C*

  Clear stack of commands

  Cn

  Clear last n commands

  O C=(E,L); D=1 or n; L=Y or N;
  W=S or A; R=(C,D,A,T)

  (all on one line; start with letter O; defaults are underlined; use parentheses as shown)

  C - company type: engines or ladders or both

  D - response level: up to nth-due

  L - box listings, Yes or No

  W - weight by structural (S) or all alarms (A)

  R - which regions to produce output for

    C - by Company

    D - by Demand region

    A - for Affected region

    T - Target hazards

  E

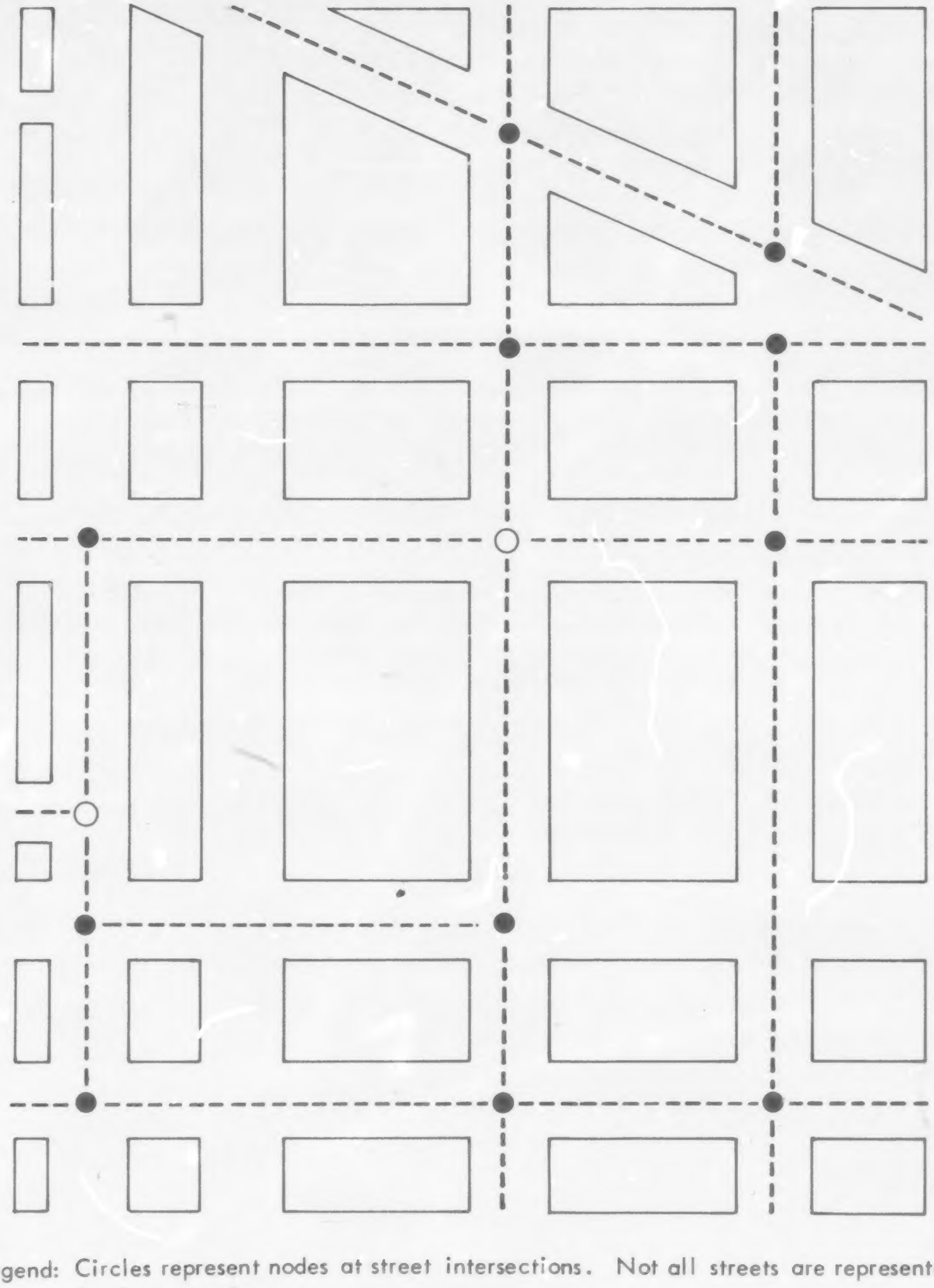
  Exit from program

- Siting model prints results side-by-side for "current" and "proposed" configurations

  -- Facilities comparisons

References and Notes

Ref.: Dormont, Hausner, and Walker, Firehouse Site Evaluation Model: Description and User's Manual



Legend: Circles represent nodes at street intersections. Not all streets are represented in the network.

Fig. LF-1 — Street network concept: nodes and links

Company: ____________

Codes:

Weather condition D = dry
W = wet

Traffic condition L = light
M = moderate
H = heavy

Usual route followed U = usual
D = detour

Due 1E = first engine
2L = second ladder

Odometer before responding	Odometer before returning	Duration of run min.	Duration of run sec.	Alarm box number	Time out Hr.	Time out Min.	Time out AM PM	Weather condition	Traffic condition	Due	Usual route followed
1234	1252	03	12	0221	06	51	AM	W	L	1E	U
3590	3607	01	03	0172	12	13	PM	D	M	2L	D
							M				
							M				
							M				
							M				
							M				
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Fig. LF-2 — Sample data form for travel-time experiment

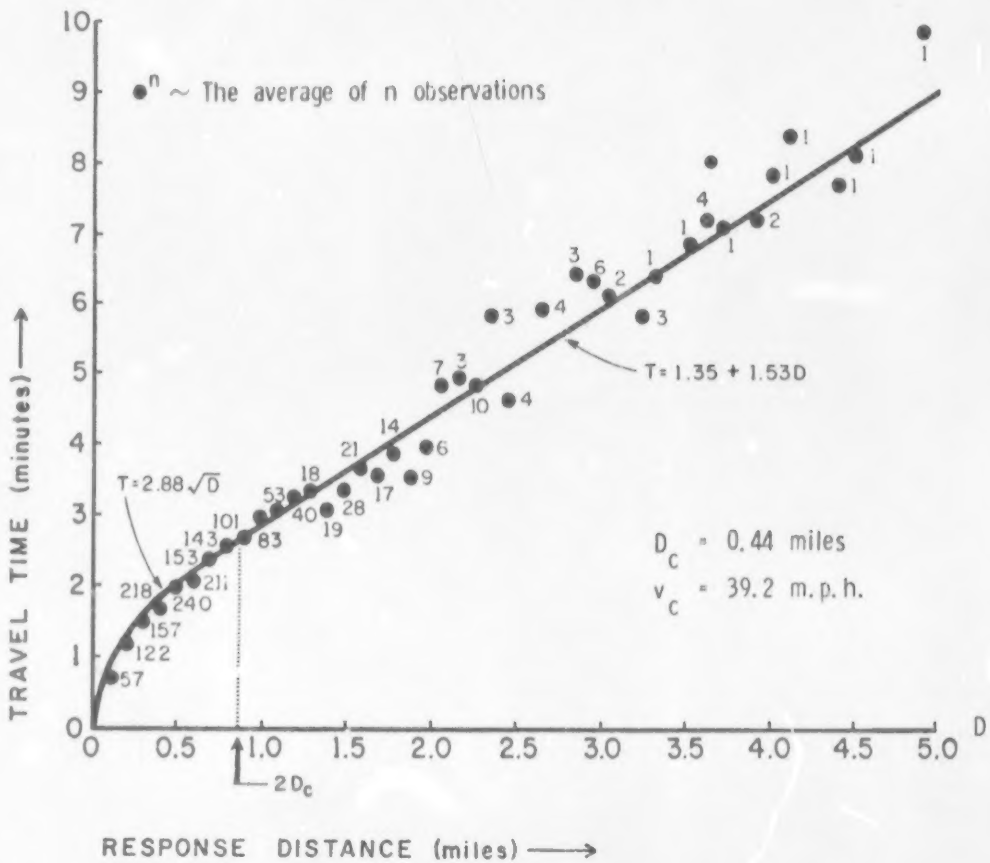


Fig. LF-3 — Graph of travel time versus response distance for New York City

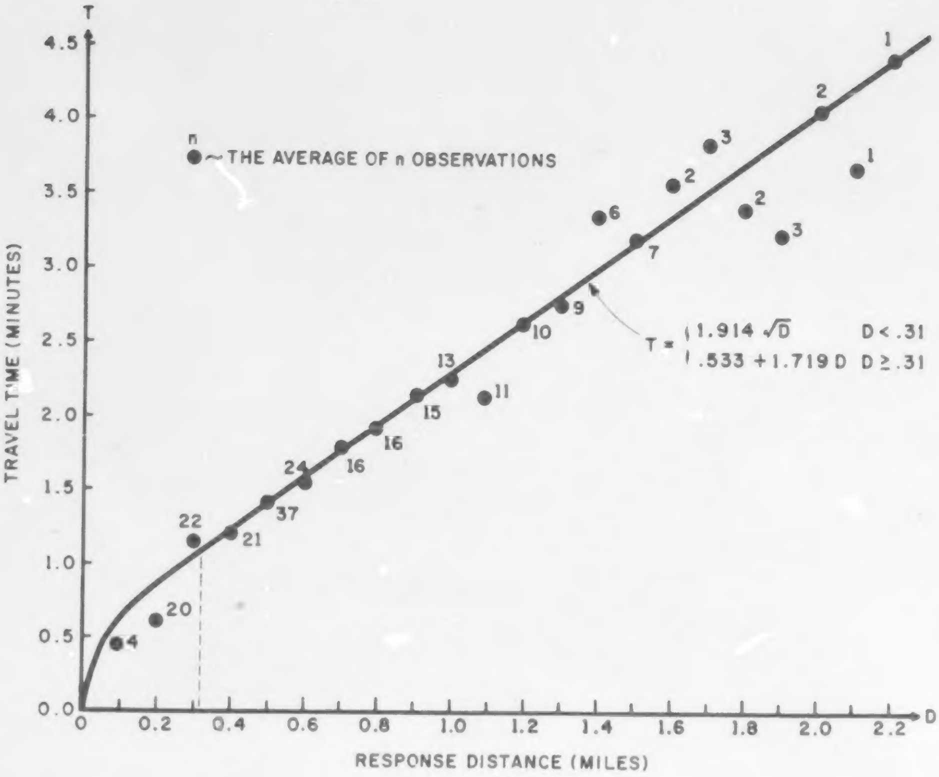


Fig. LF-4 — Graph of travel time versus response distance for Trenton, New Jersey

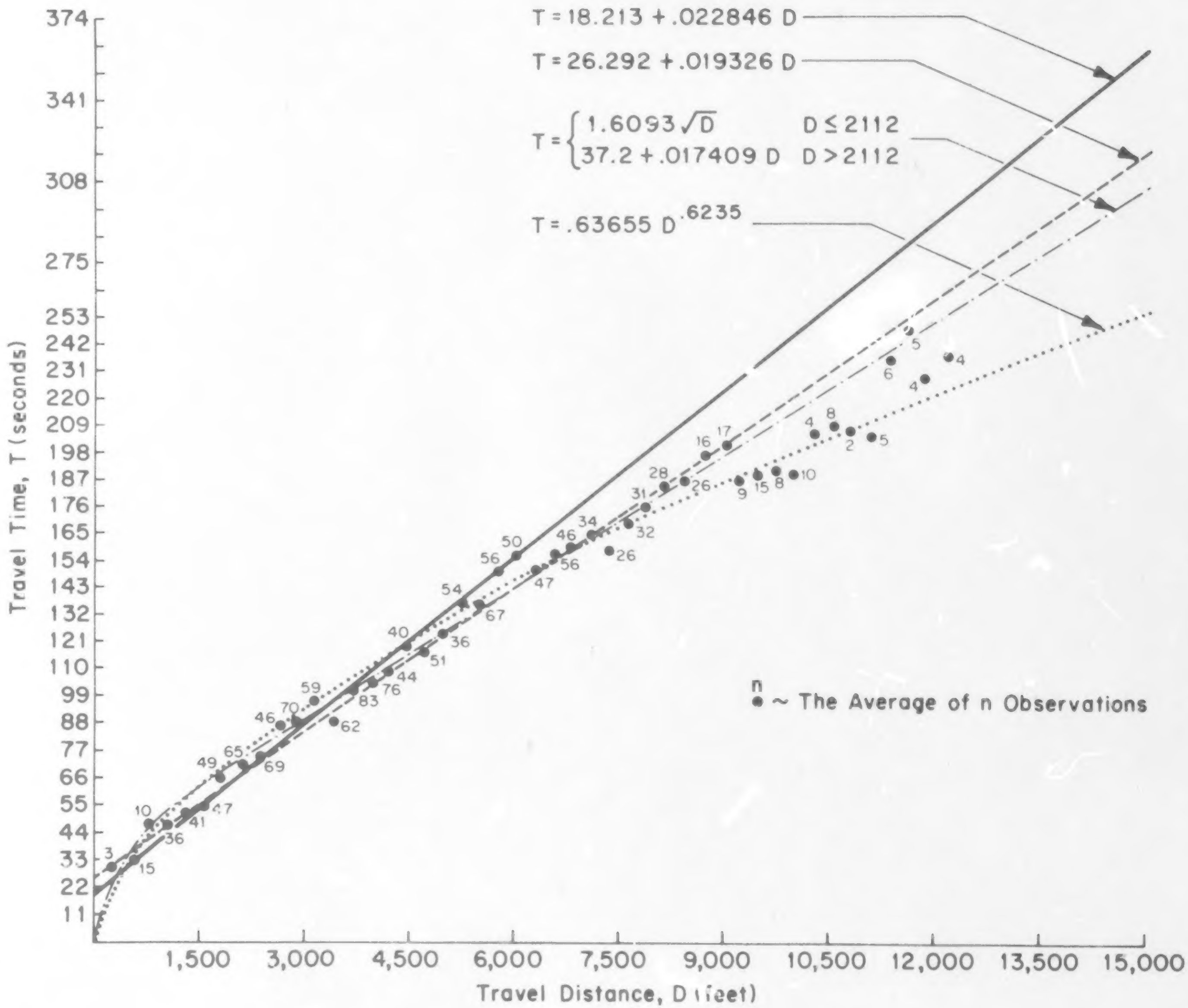


Fig. LF-5 — Graph of travel time versus response distance for Denver, Colorado

LECTURE SF

SIMULATION
FOR FIRE SERVICE AUDIENCES

Time: Approx. 50 minutes

Objective: To describe what a simulation model does, what kinds of questions it can answer, when to use it, and what resources are needed to use it.

Activity	References and Notes
1. DEFINITION • Follow each incident step-by-step: From occurrence -- to report to fire department -- to dispatch of companies -- to their arrival at scene and work there -- to their return to availability • Do this for a large number of incidents -- actual incidents, or -- imaginary incidents generated by the computer to match average statistics for alarm rates, etc. • Viewpoint of an "all-knowing" dispatcher who keeps track of the location of all incidents and companies at all times, but is not concerned with fire-fighting tactics at the scene • Computer collects statistics on response times, coverage, workloads	Lecture follows Carter, Chaiken, and Ignall, Simulation Model of Fire Department Operations: Executive Summary See also, Carter and Ignall, A Simulation Model of Fire Department Operations: Design and Preliminary Results

Activity	References and Notes
2. WHY SIMULATE?	
• Accuracy compared to other models (at a price)	
-- Removes approximations present in every simple model	
-- Accounts for interrelationship among policies that can be individually studied with simple models	"Policy" = location of stations, dispatch policy, relocation policy, etc.
• Safety as opposed to real-world test	
-- No operational or capital investment	
-- No lives or property risked	
-- The model can imagine that alarm rates "stay the same" after policy changes, but in the real world alarm rates will change	I.e., changes in real-world data may reflect changes in alarm rate, changes in policy, or both together
3. DRAWBACKS	Discussed in detail later in this lecture
• Simulation is expensive to run on the computer	
• Extensive data collection needed	
• Simulation does not suggest any particular policy as desirable	
• User must be technically skilled	

Activity	References and Notes
4. WHEN TO USE A SIMULATION MODEL	
• Detailed comparison of complicated deployment policies -- Number of companies on duty -- Where located -- Number of units dispatched to particular types of alarms -- Which unit(s) dispatched -- When units are relocated (moved up) -- Which units are moved and where they go	Ref.: Carter, Ignall, and Walker, A Simulation Model of the New York City Fire Department: Its Use in Deployment Analysis
• Validation of simpler models, which are -- Cheaper to use -- Easier to interpret	Ref.: Ignall, Kolesar, and Walker, Using Simulation to Develop and Validate Analytical Emergency Service Deployment Models
• Instill confidence in administrators that final recommendations will work as planned, especially under adverse circumstances	See Tomasides quote in Carter, Chaiken, and Ignall, Simulation Model of Fire Department Operations: Executive Summary, and Hendrick et al., An Analysis of the Deployment of Fire-Fighting Resources in Denver, Colorado
5. WHERE DO THE POLICIES COME FROM, TO TEST ON A SIMULATION MODEL?	
• Fire department administrators	
• Planning personnel	
• Simpler models	Lectures OF, AF, LF, IF

Activity	References and Notes
6. HOW DOES THE NYCRI SIMULATION MODEL WORK?	
• Discuss flow chart	Develop the flow chart on the blackboard, writing down each event as the incident progresses. The final result is Figure SF-1. Ref.: Carter, Simulation Model of Fire Department Operations: Program Description
7. WHAT INFORMATION IS IN THE SIMULATION OUTPUT	
• Response times -- Average and distribution -- By incident type -- By geography • Company workloads -- Total -- By company • Coverage	Stress the detailed breakdowns available. Example output is shown on pp. 172-189 of Carter, Simulation Model of Fire Department Operations: Program Description

Activity	References and Notes
8. DATA AND RESOURCES NEEDED	Stress the detail required, as compared to other models
• Geographical representation of the part of the city to be simulated -- Incident locations -- Company locations	
• Parameters for estimating travel time of every response	I.e., a complete mathematical specification of the curves in Figures LF-3 to LF-5. These may vary in different parts of the city
• Work times at different types of incidents	
• An input stream of incidents -- Actual incidents from the past -- or, incidents generated from detailed data about alarm rates by type and location	
• Deployment policy -- Detailed decision rules for dispatching and relocation	
• Access to a SIMSCRIPT I.5 compiler	
• Analysts who can modify the computer program and interpret the output	
9. VALIDITY (Optional)	
• Detail and structure have to be sufficient to support insights and conclusions	
• What matters is the accuracy of comparisons, not faithfulness to the real world Example: If all travel times are 10 percent high, this should not make any difference. (On the other hand, it would be easy to fix)	

Activity | References and Notes

10. RECAP

- Computer's job: do the bookkeeping
- User's job
  - -- Build model: specify how the system works
  - -- Analyze data: specify the kind of data needed (and get it)
  - -- Select criteria: specify what is to be measured
  - -- Find alternatives: specify the policies to be tried out in the simulation

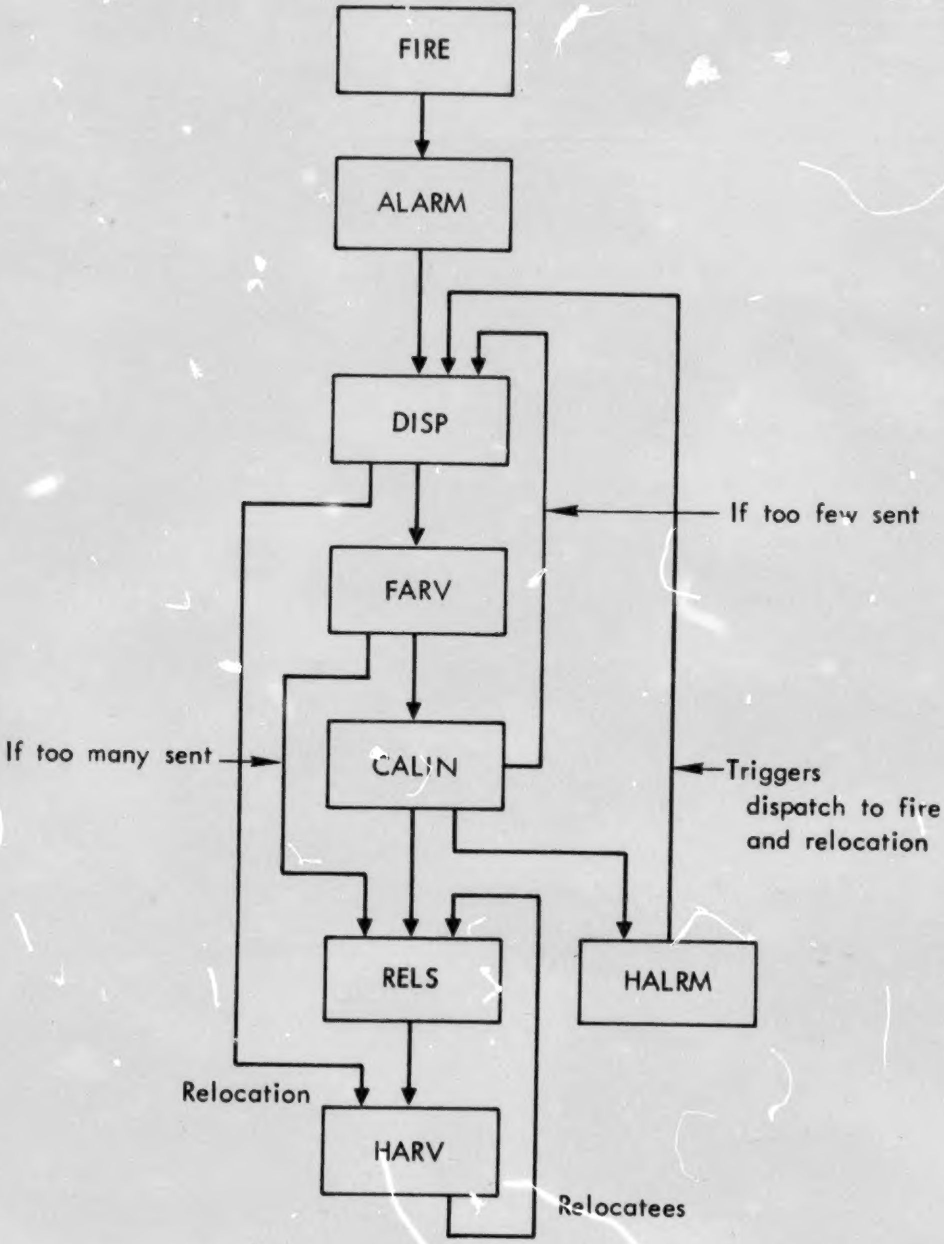

FIRE
ALARM
DISP
FARV
CALIN
RELS
HALRM
HARV
If too few sent
If too many sent
Triggers dispatch to fire and relocation
Relocation
Relocatees

Fig. SF-1

LECTURE MF

RELOCATION OR MOVE-UP
FOR FIRE SERVICE AUDIENCES

Time: Approx. 40 minutes (demonstration extra)

Objective: To indicate difficulties with a system of preplanned relocations and demonstrate a method for resolving the difficulties.

Equipment: Portable terminal with acoustic coupler for demonstration.

Activity	References and Notes
1. INTRODUCTION: RELOCATION ISSUES	
• When should fire companies relocate (move up)?	
• How many should relocate?	
• Which ones?	
• To where?	
2. PREPLANNED RELOCATIONS	
• Problems at high alarm rates	Figure MF-1
-- Several "all hands" fires in one part of the city can create a "hole" in coverage as big as if there were one second-alarm or third-alarm fire	
-- Company designated to relocate may already be busy at a fire	
-- Company designated to relocate may be available, but moving it would create another big hole in coverage	

Activity	References and Notes
3. NYCRI APPROACH	Follows Kolesar and Walker, An Algorithm for the Dynamic Relocation of Fire Companies
• Answer the four questions posed in the Introduction, one at a time	
• Separate (but same) calculations for engines and ladders (will use ladders as an example)	
Question 1: When should fire companies relocate?	
Answer: Relocate whenever some location in city has both its first-due and second-due ladders unavailable, and they will be unavailable for a period of time	
-- Define a ladder response neighborhood (RN) as all points in the city having the same first- and second-due ladders, independent of order	
-- If both are unavailable, and will be for awhile, the RN is "uncovered"	
-- Result: Relocate whenever there is an uncovered RN in the city	
-- This criterion maintains relative spacing of fire companies throughout the city (denser in some regions than others)	Figure MF-2
Question 2: How many should relocate?	
Answer: If there are any uncovered RNs, fill the minimum number of houses needed to remedy the situation	Figure MF-3

Activity	References and Notes
3. NYCRI APPROACH (continued) Question 3: Which companies should move? Answer: Choose companies to satisfy four general principles (a) Don't relocate a company that will create a new uncovered RN (b) Don't relocate a company that is "too busy"	
• First-due areas the same size More alarms around #2 Same distance to X -- If move #1, second-due unit will be the first-arriving unit in the first-due area of #1 -- Similar if move #2 -- More likely to have a fire near #2 -- Therefore, prefer to move #1	Figure MF-4
(c) Don't relocate a company that is covering too large a region • First-due area of #1 larger Same number of alarms in both Same distance to X -- Average first-due travel time already higher area of #1 -- If move #1, average travel time for second-due company to respond to region #1 will be much higher than in region #2 -- Prefer to move #2	Figure MF-5

Activity | References and Notes

3. NYCRI APPROACH (continued)

Question 3 (continued)

(d) Don't relocate a company "too far"

Figure MF-6

- First-due areas of #1 and #2 the same size
  Same alarm rate
  #2 is farther

-- If relocated, #2 would be out of its region longer than #1 would be

-- Therefore, chance of missing an alarm in its region would be higher for #2 than for #1

-- Prefer to move #1

Note: Real cases are a mixture of different alarm rates, different sized areas, and different relocation distances. Developed a "cost" function that blends all these things

- Represents the expected average travel time for first-arriving unit to alarms in the area affected by the moves (areas whose first-due travel times will be changed) during the duration of the moves
- Objective: Choose units to move that minimize this "cost"
- Note: The cost function assumes that while the companies are relocating they are not protecting either their own area or their destination area

Question 4: Where do the companies move?

Answer: Assign relocating companies to the houses being filled so as to minimize the total travel time of the relocating companies

- "Cost" will be higher than minimum, but only slightly
- Relocations will "look better"

Activity

4. DATA NEEDED

(a) For each firehouse

- Number and identity of units stationed there
- List of RNs associated with each of the companies
- Size of each first-due area, in square miles
- Alarm rate in each first-due area

(b) For each RN

- Size of area in which each of the two units is first-due
- Alarm rate in each of the two areas

(c) For each pair of houses

- Travel time from one to the other

(d) Parameters for relating travel time and area, so that travel times in each region can be estimated from their areas

5. APPLICABILITY

- Method requires a real-time computer to make calculation based on the actual status of all fire companies
- Method can be used to generate relocations to be specified on running cards, in which case it is not operated in real time. (But not all situations requiring a relocation are handled well by running cards)

References and Notes

Shanesy, An On-Line Program for Fire Company Relocation

RN = response neighborhood

Refer to Lecture RF

Activity	References and Notes
6. DEMONSTRATION OF ON-LINE RELOCATION PROGRAM SCENARIO 1	
This demonstration compares manually developed relocations with what the program does, revealing that neither way is perfect. Geography corresponds to the borough of the Bronx in New York City	A sequence of commands to the program is shown. Interpretation of the commands is given in Shanesy, *An On-Line Program for Fire Company Relocation*
`MICS`	
`M=NOVERIFY` `E=MNE,MNL,QNE,QNL`	Otherwise you need larger maps
`1:R=E63,E62,L39,L32` `S=1`	First line of AAC (Figure MF-7)[*]
`(CR)`	
`2:S=E38,E79,E48,E97,L51`	Second alarm
`C=EW,LW`	
`DEP2P:D=EW,LW`	Situation is shown on Figures MF-8, MF-9. Compared to running card (Figures MF-10, MF-11) the number of engine relocations is smaller
`3:S=E75,E90,E81,L46`	This is a reasonable variant on AAC third alarm
`C=EW,LW`	Recommendations shown on Figures MF-12, MF-13. Note that a previously empty house is filled
`Q=3` `U=DEP2P`	Let's go back to second alarm
`DEP2C:D=E81,QE63;E43,QE62;E50,QE79;E89,QE97;` `L46,QL39;L50,QL51`	Follow the AAC
`(CR)`	All RNs are covered
`3C:S=E75,E90,E88,L37` `C=EW,LW`	Needs only one more engine relocation. The AAC "anticipated" a third alarm
`/*`	Exit

---

[*] AAC and maps were current in 1973.

Activity	References and Notes
7. SCENARIO 2	
- Invent a sequence of small fires that leads to a need for relocation	Use blank maps for the Bronx (Figures MF-14, MF-15) or maps for a city familiar to members of the audience If lecturer has access to on-line relocation program, it will recommend relocations

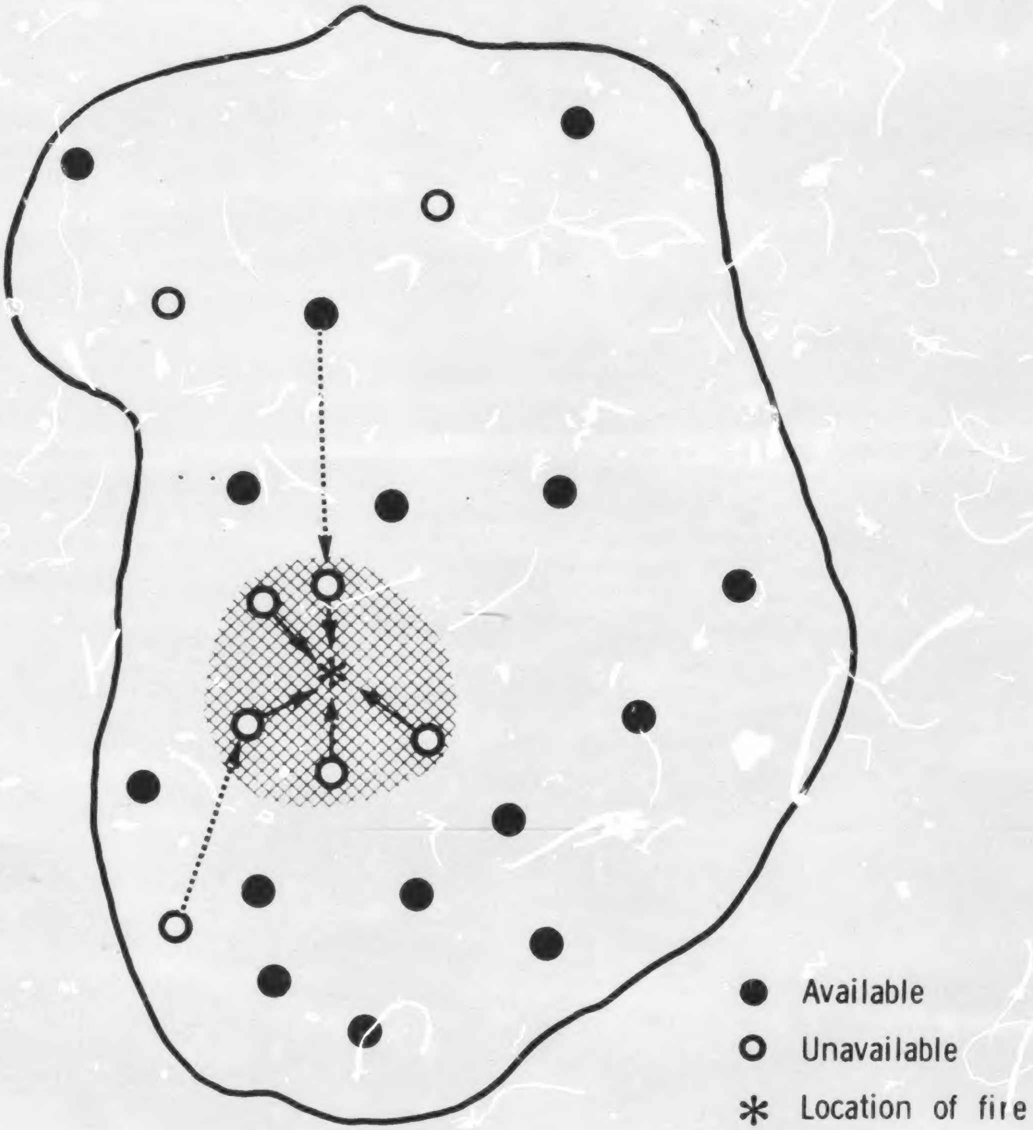
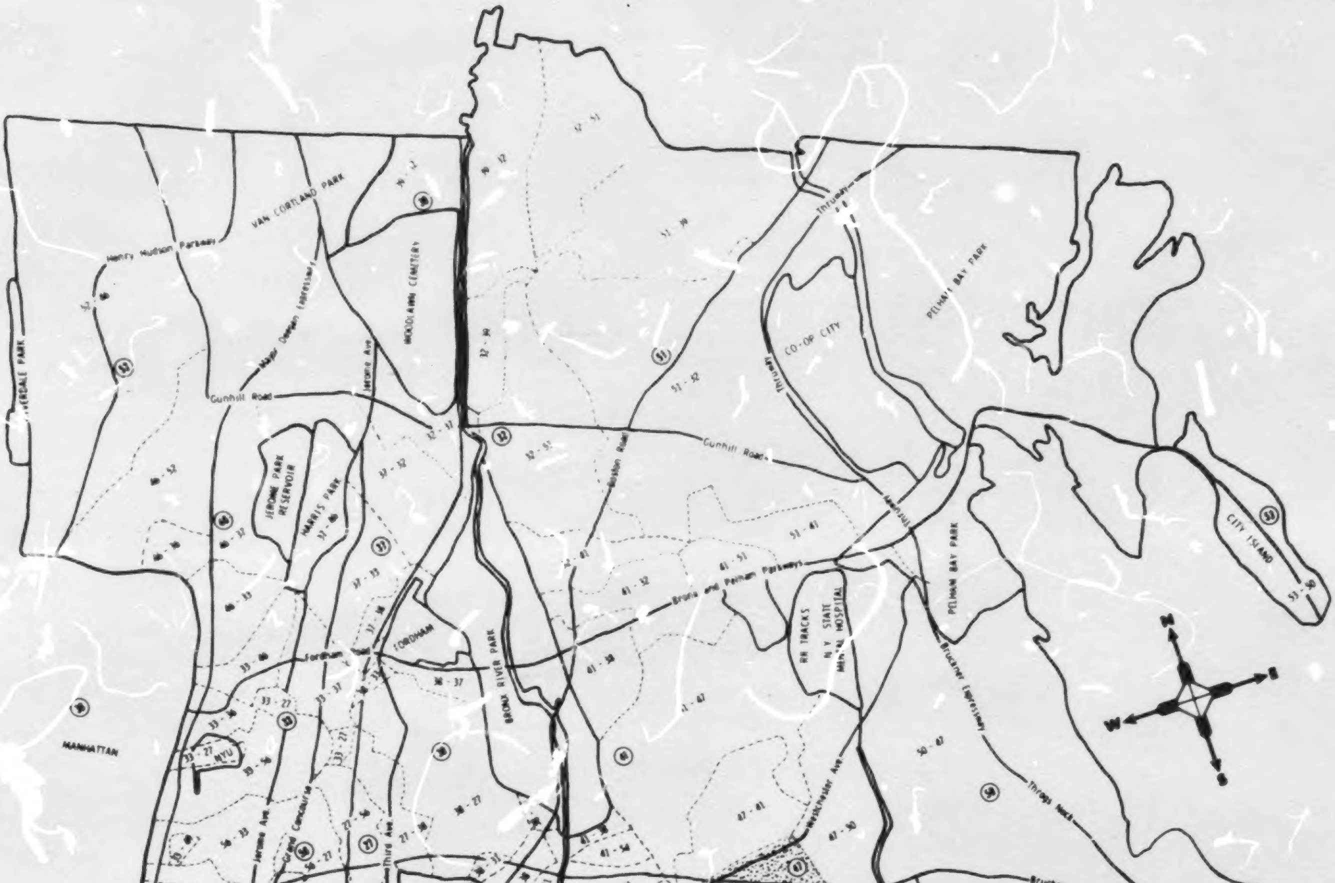

● Available
○ Unavailable
* Location of fire

Fig. MF-1 — Problems with the traditional relocation policy


VAN CORTLAND PARK
Henry Hudson Parkway
Major Deegan Expressway
WOODLAWN CEMETERY
RIVERDALE PARK
Gunhill Road
JEROME PARK RESERVOIR
HARRIS PARK
FORDHAM
Fordham Road
BRONX RIVER PARK
Bronx and Pelham Parkways
Thruway
CO-OP CITY
PELHAM BAY PARK
CITY ISLAND
N. Y. STATE MENTAL HOSPITAL
RR TRACKS
Bruckner Expressway
Throgs Neck
MANHATTAN
NYU
Cross-Bronx Expressway
CLAREMONT PARK
CROTONA PARK
Westchester Ave
WESTCHESTER CREEK
FERRY POINT PARK
BRONX RIVER
ST. MARY PARK
Hills Ave. Bridge
Tri-Boro Bridge
N
E
S
W

Response neighborhoods shaded

Legend: 47-54 means ladder 47 is first-due and ladder 54 is second-due. A response neighborhood corresponds to two ladders, independent of their arrival order.

Fig. MF-2 — Ladder response neighborhoods in the Bronx.

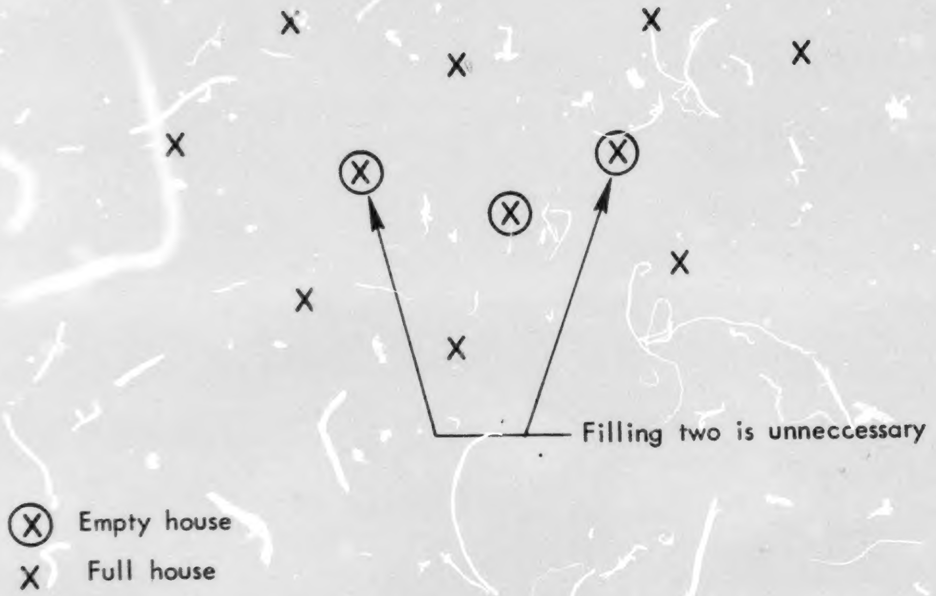

Filling two is unneccessary
Ⓧ Empty house
X Full house

Fig. MF-3

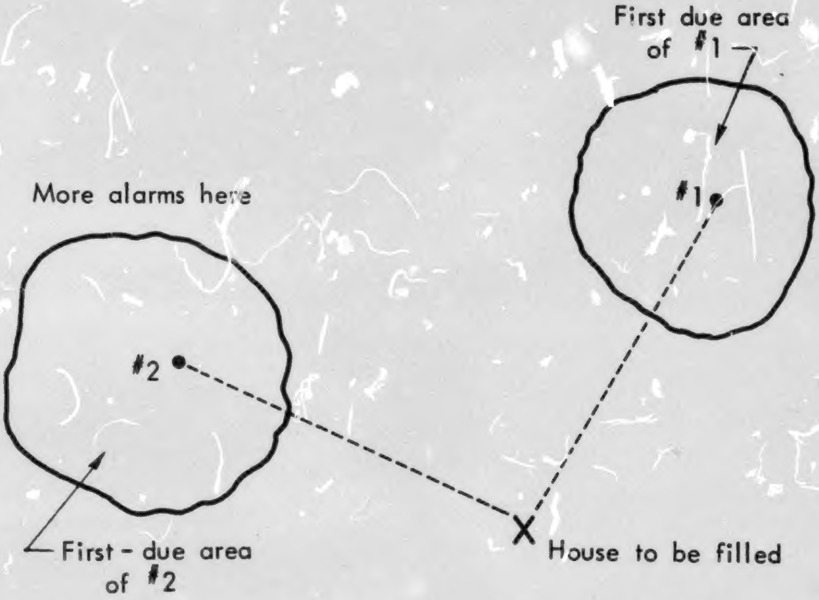

First due area
of #1
#1
More alarms here
#2
First - due area
of #2
House to be filled

Fig. MF-4

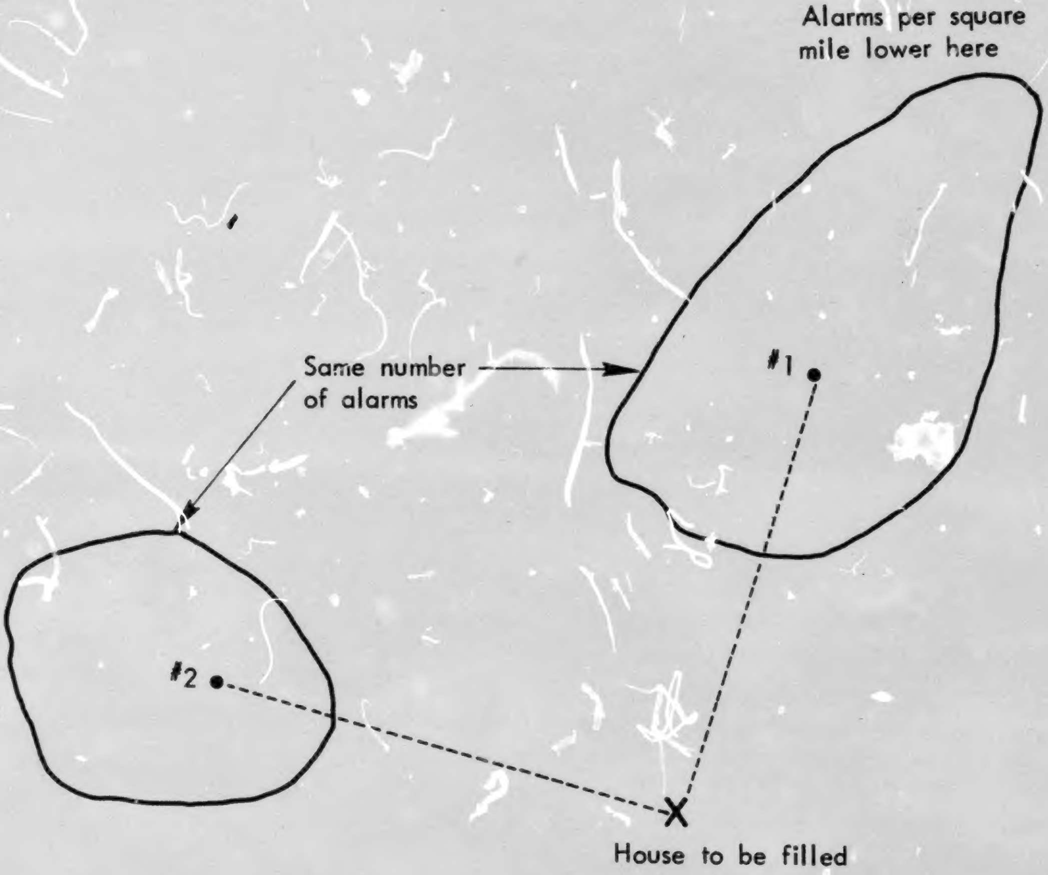

Alarms per square mile lower here
Same number of alarms
#1
#2
House to be filled

Fig. MF-5

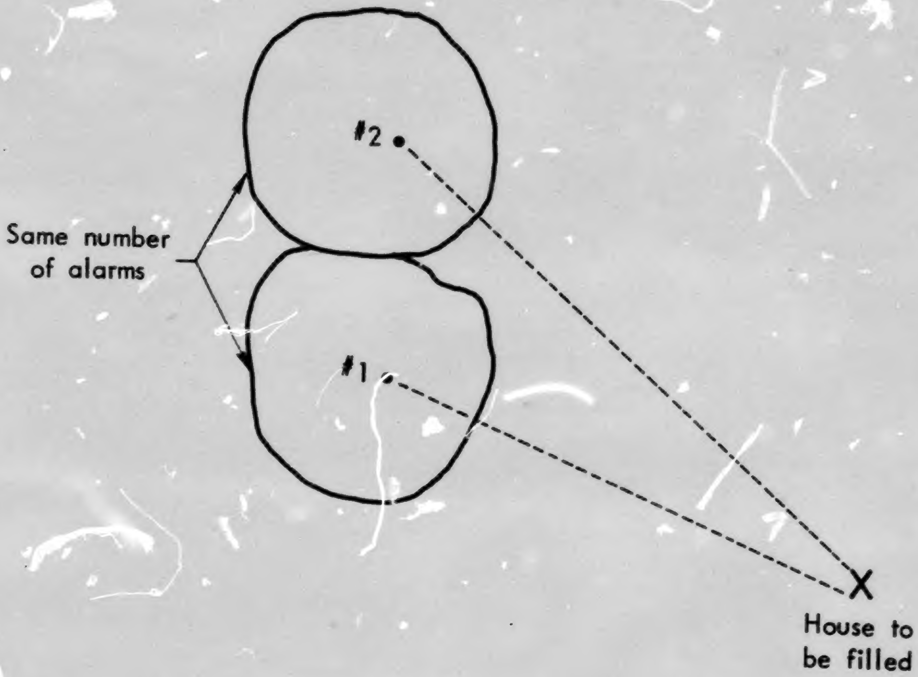
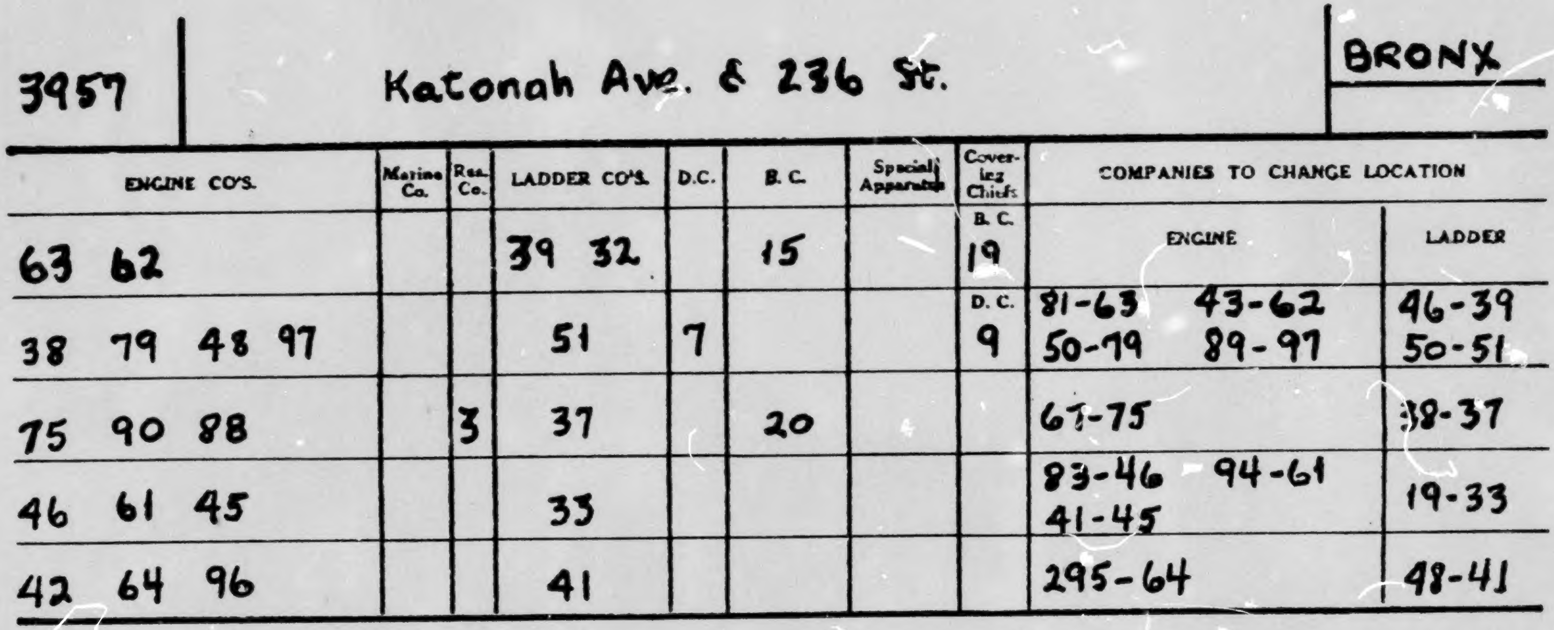

#2
#1
Same number of alarms
House to be filled

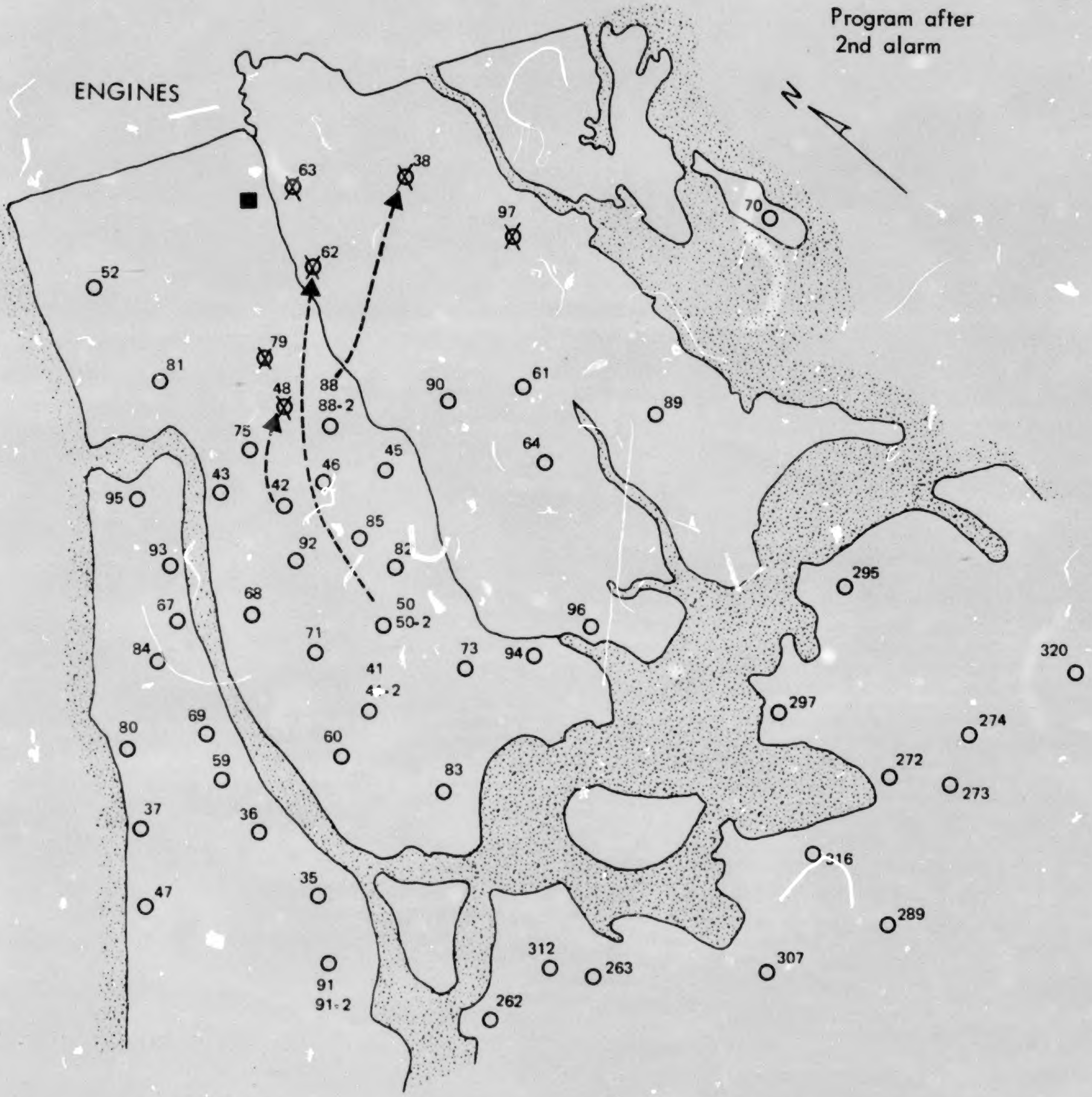
Fig. MF-6



3957 | Katonah Ave. & 236 St. | BRONX

ENGINE CO'S.	Marine Co.	Res. Co.	LADDER CO'S.	D.C.	B.C.	Special Apparatus	Cover-ing Chiefs	COMPANIES TO CHANGE LOCATION	
								ENGINE	LADDER
63 62			39 32		15		B.C. 19		
38 79 48 97			51	7			D.C. 9	81-63 43-62 50-79 89-97	46-39 50-51
75 90 88		3	37		20			67-75	38-37
46 61 45			33					83-46 94-61 41-45	19-33
42 64 96			41					295-64	48-41

Fig. MF-7—Alarm assignment card (AAC) for Bronx box 3957


Program after
2nd alarm
ENGINES
N
63
38
97
70
62
52
79
81
48
88
88-2
90
61
89
75
64
45
46
43
42
95
85
92
82
93
295
67
68
50
50-2
96
84
71
73
94
320
41
41-2
297
274
80
69
60
59
83
272
273
37
36
316
35
47
289
312
263
307
91
91-2
262

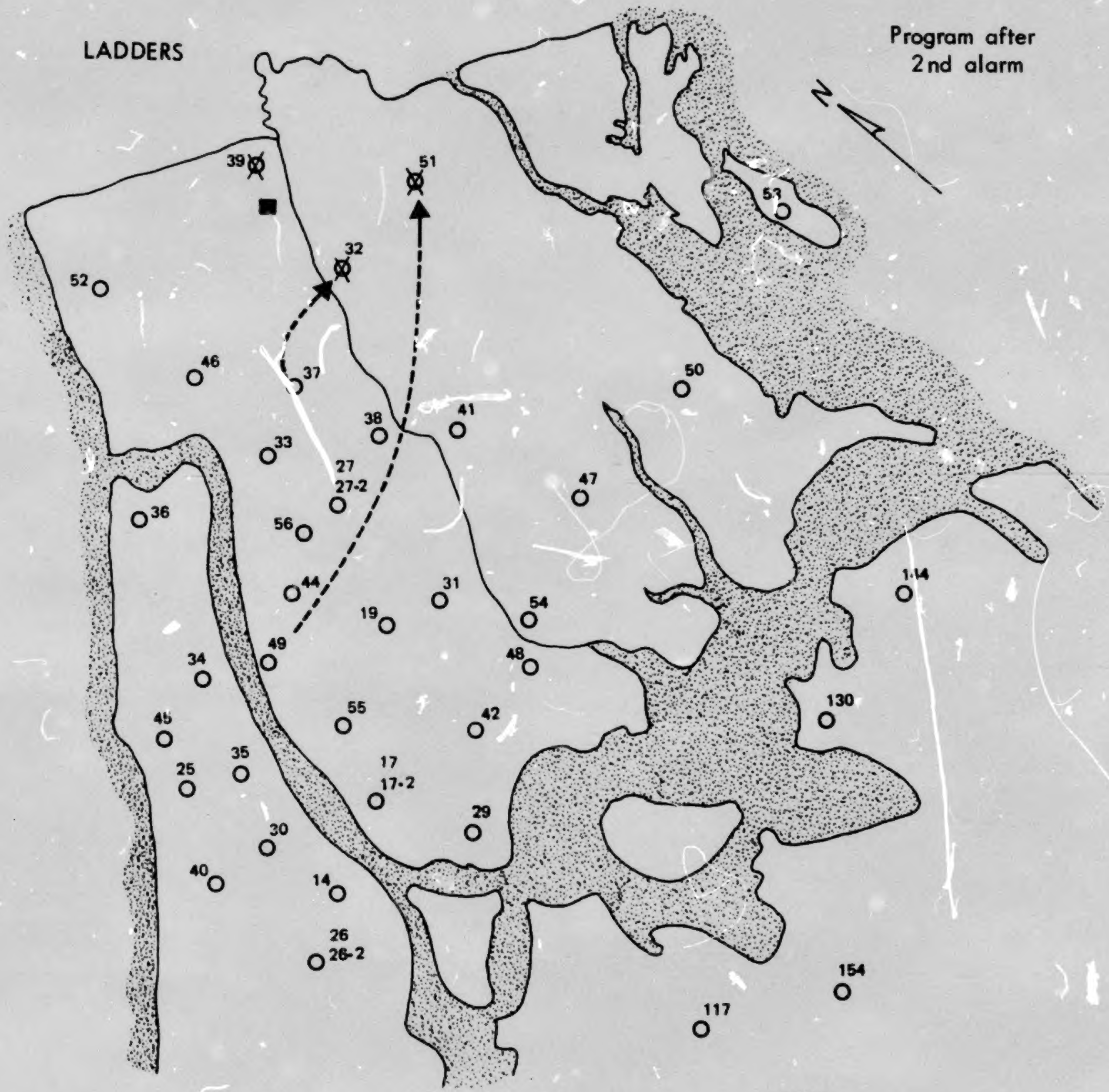
LEGEND :

○ Fire station with all companies available
⊗ Company has just been dispatched to a fire
∅ One company remains in a station which usually has two companies
● Station is vacant by virtue of a previous dispatch

LEGEND :

R○ Station is occupied by a relocated unit
◉ Station is vacant by virtue of a previous relocation
——▶ Dispatch
- - - -▶ Relocation
■ Location of a fire

Fig. MF-8


LADDERS
Program after
2nd alarm
N
39
51
32
53
52
46
37
50
38
41
33
27
27-2
47
36
56
144
44
31
54
19
49
48
34
55
42
130
45
35
25
17
17-2
29
30
40
14
26
26-2
154
117

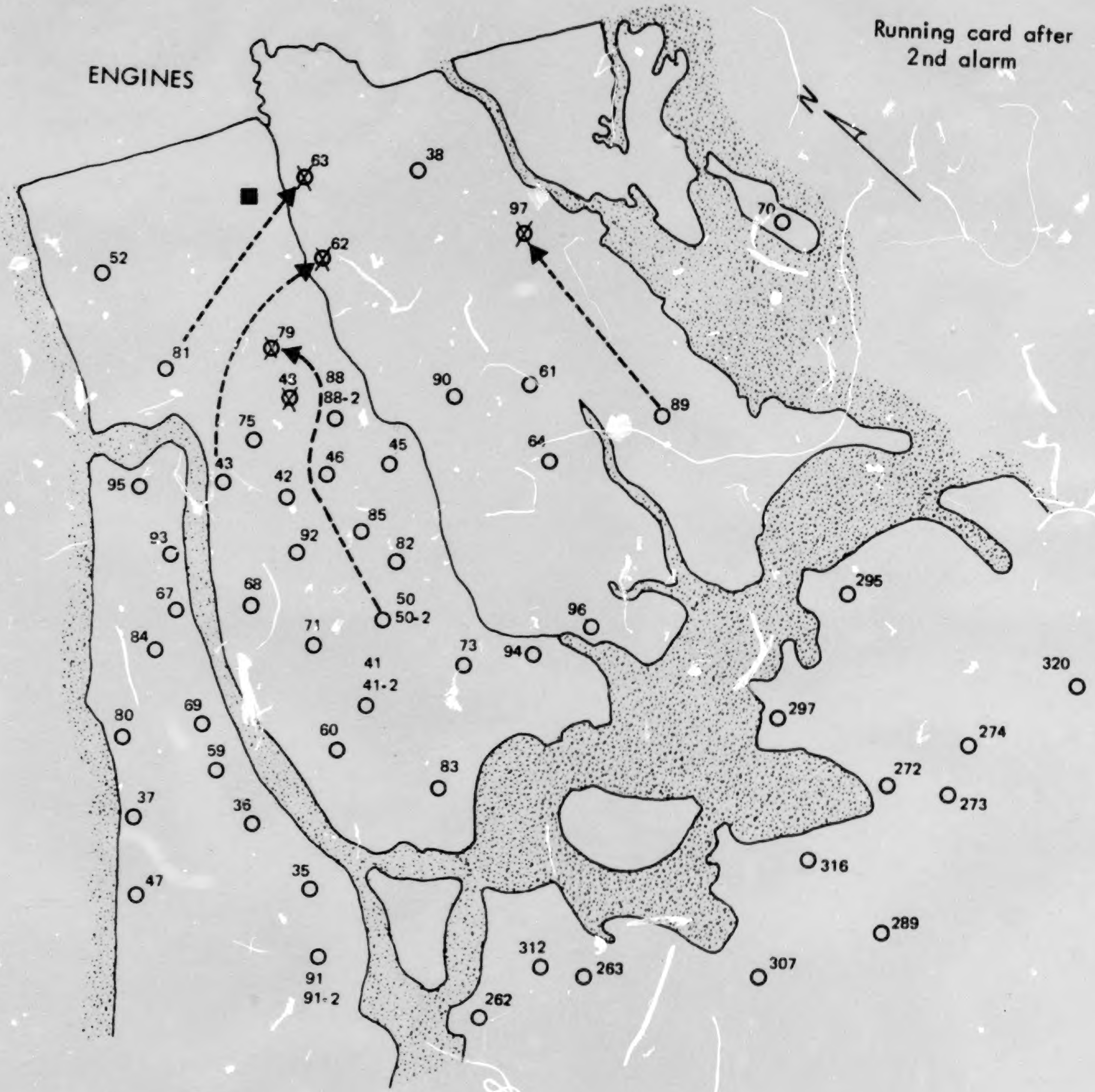
LEGEND :

○ Fire station with all companies available
☒ Company has just been dispatched to a fire
ø One company remains in a station which usually has two companies
● Station is vacant by virtue of a previous dispatch

LEGEND :

^{R}○ Station is occupied by a relocated unit
◉ Station is vacant by virtue of a previous relocation
⟶ Dispatch
- - -▶ Relocation
■ Location of a fire

Fig. MF-9


ENGINES
Running card after 2nd alarm
N
63
38
97
70
52
62
81
79
43
88
88-2
90
61
89
75
45
64
95
43
42
46
85
93
92
82
68
67
50
50-2
295
96
71
84
73
94
41
41-2
320
297
80
69
60
274
59
83
272
37
273
36
316
35
47
289
312
263
307
91
91-2
262

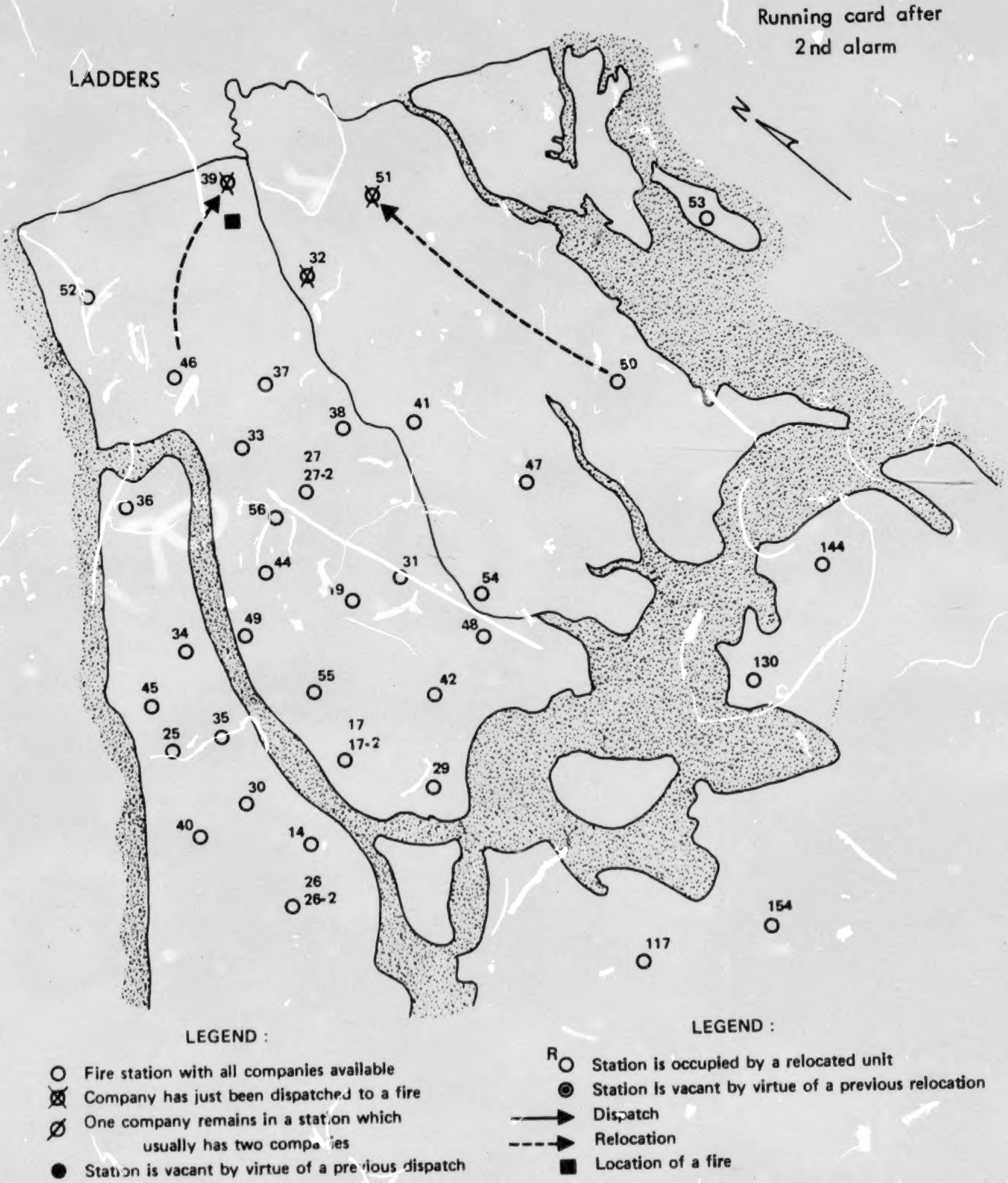
LEGEND :

○ Fire station with all companies available
⊠ Company has just been dispatched to a fire
∅ One company remains in a station which usually has two companies
● Station is vacant by virtue of a previous dispatch

LEGEND :

R○ Station is occupied by a relocated unit
◉ Station is vacant by virtue of a previous relocation
——► Dispatch
----► Relocation
■ Location of a fire

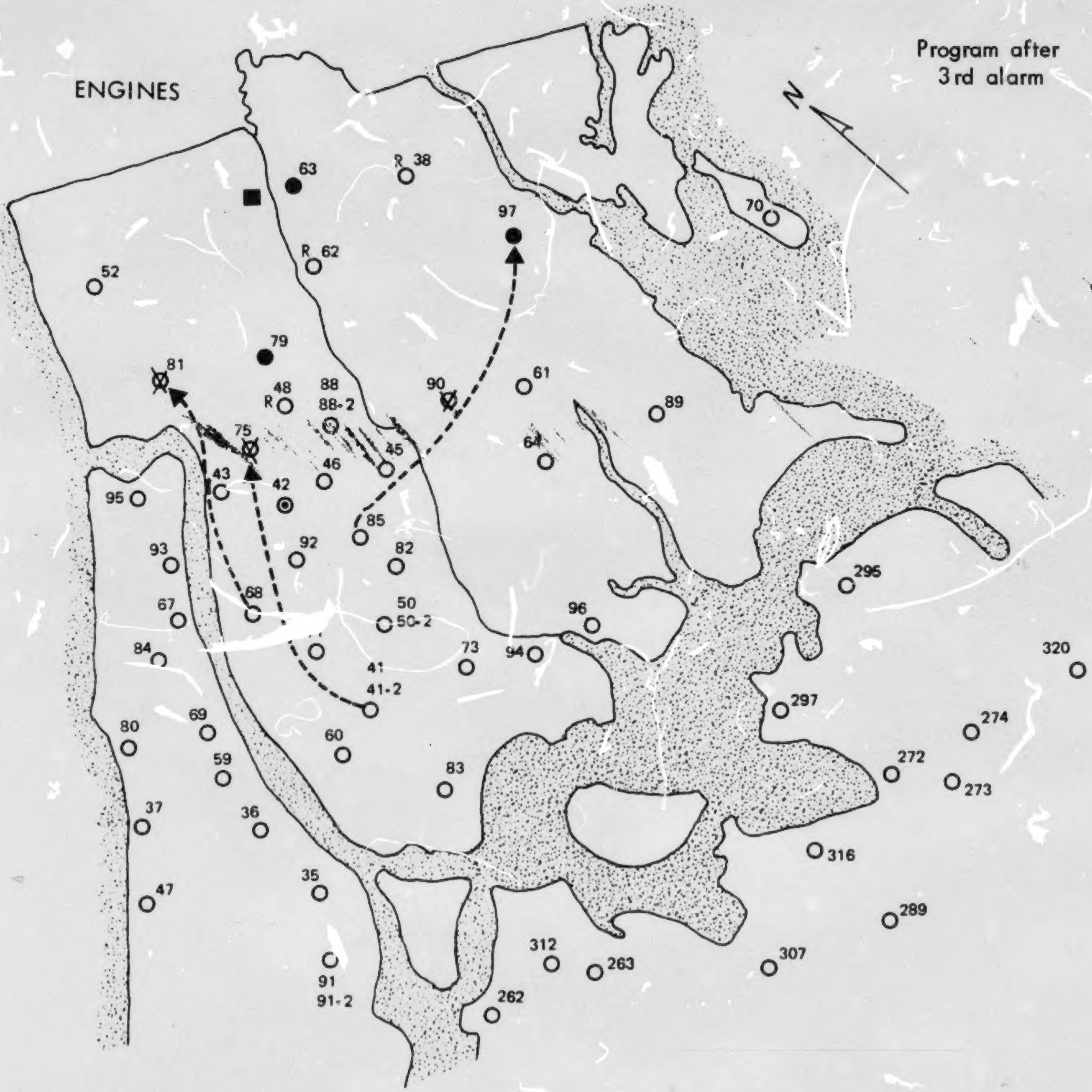
Fig. MF-10



Running card after
2nd alarm

LADDERS
N
39
51
53
32
52
46
37
50
38
41
33
27
27-2
47
36
56
144
44
31
19
54
49
48
34
130
45
55
42
35
17
17-2
25
29
30
40
14
26
26-2
154
117
LEGEND :
○ Fire station with all companies available
Company has just been dispatched to a fire
ø One company remains in a station which usually has two companies
● Station is vacant by virtue of a previous dispatch
LEGEND :
R○ Station is occupied by a relocated unit
◉ Station is vacant by virtue of a previous relocation
Dispatch
Relocation
■ Location of a fire

Fig. MF-11


ENGINES
Program after 3rd alarm
N
R 38
63
97
70
R 62
52
79
81
48
88
88-2
90
61
89
75
45
64
43
42
46
95
85
92
82
93
68
50
50-2
67
96
295
84
73
94
41
41-2
320
297
274
80
69
59
60
83
272
273
37
36
316
35
289
47
312
263
307
91
91-2
262
R

LEGEND :

○ Fire station with all companies available

⊗ Company has just been dispatched to a fire

⌀ One company remains in a station which usually has two companies

● Station is vacant by virtue of a previous dispatch

LEGEND :

R○ Station is occupied by a relocated unit

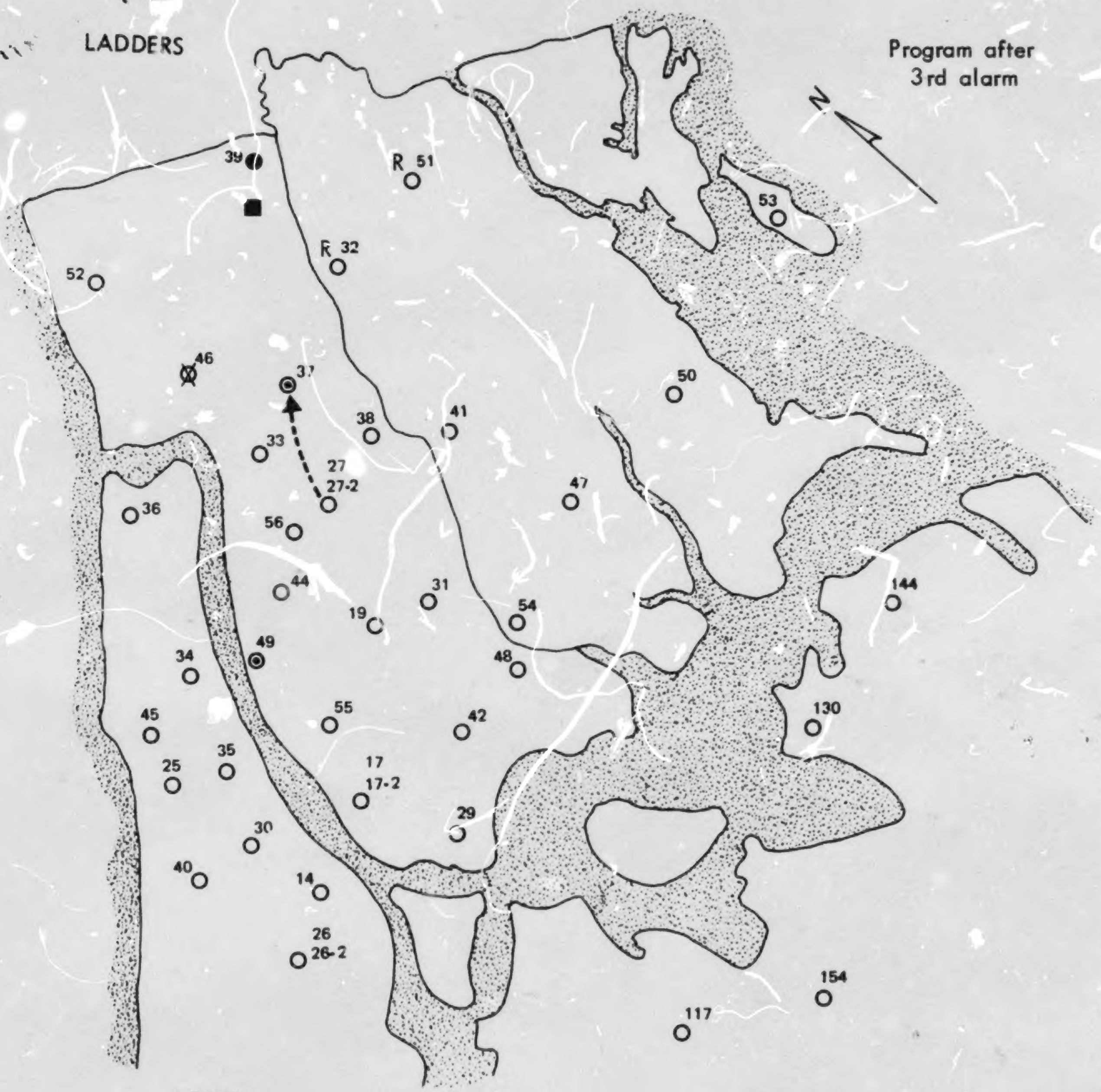
◉ Station is vacant by virtue of a previous relocation

——▶ Dispatch

- - -▶ Relocation

■ Location of a fire

Fig. MF-12


LADDERS
Program after 3rd alarm
N
39
R 51
53
R 32
52
46
37
50
38
41
33
27
27-2
47
36
56
144
44
31
19
54
49
34
48
55
42
130
45
35
25
17
17-2
29
30
40
14
26
26-2
154
117

LEGEND :

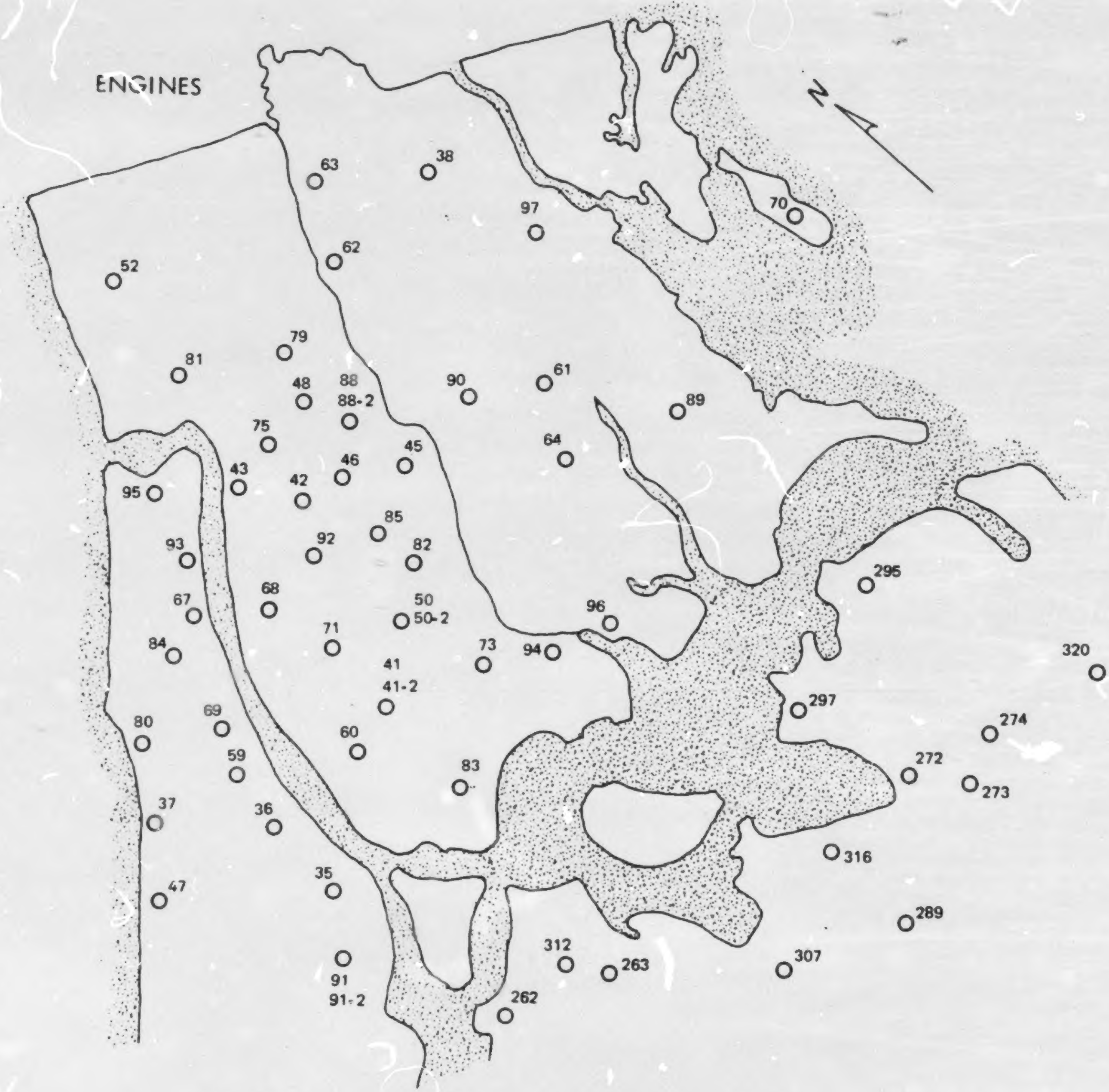
○ Fire station with all companies available
☒ Company has just been dispatched to a fire
Ø One company remains in a station which usually has two companies
● Station is vacant by virtue of a previous dispatch

LEGEND :

R○ Station is occupied by a relocated unit
◉ Station is vacant by virtue of a previous relocation
——▶ Dispatch
----▶ Relocation
■ Location of a fire

Fig. MF-13

ENGINES


N
63
38
97
70
62
52
79
81
48
88
88-2
90
61
89
75
64
45
46
43
42
95
85
92
82
93
295
68
50
50-2
67
96
71
84
73
94
320
41
41-2
297
274
80
69
60
59
272
273
83
37
36
316
35
47
289
312
263
307
91
91-2
262

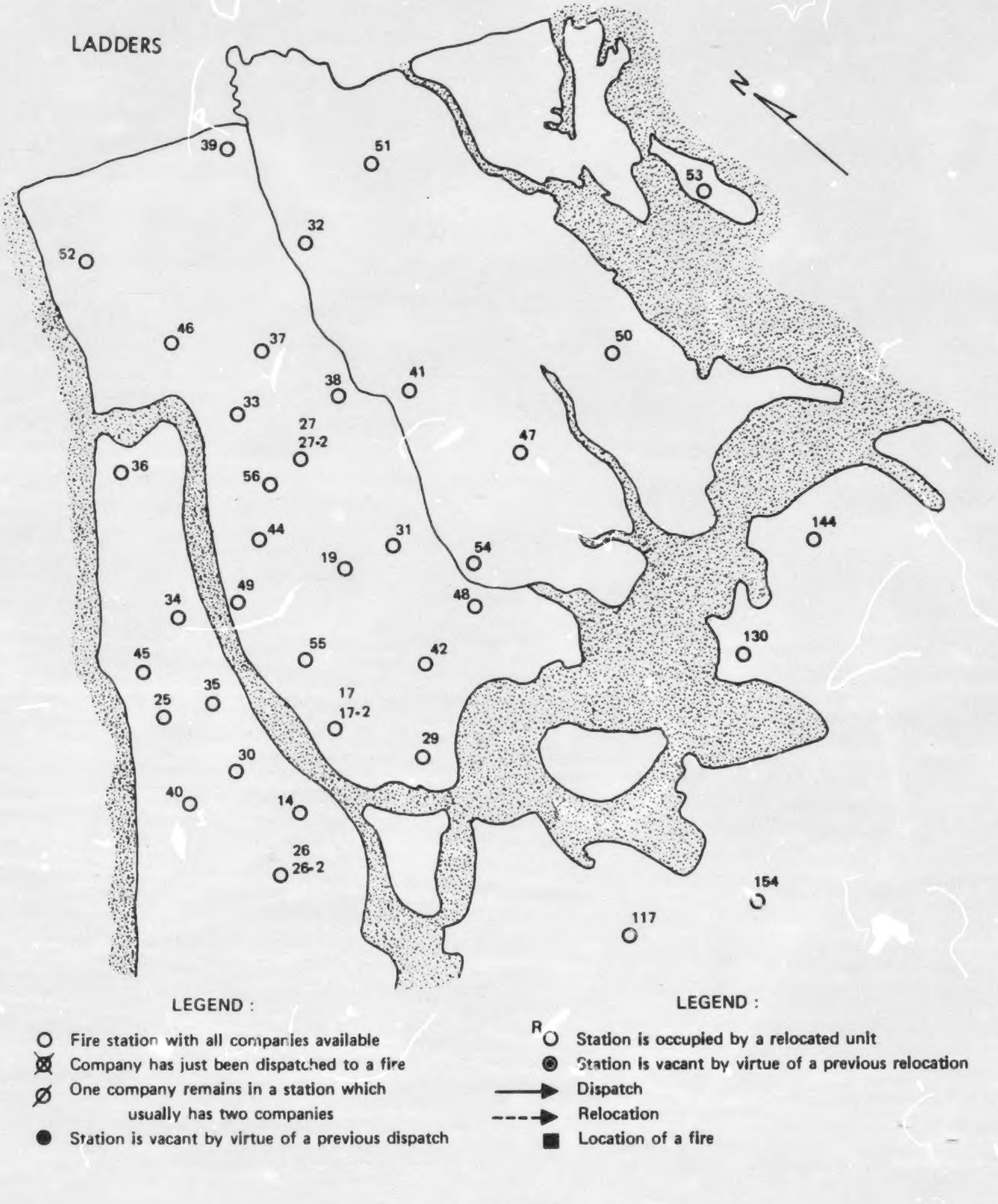
LEGEND :

○ Fire station with all companies available
☒ Company has just been dispatched to a fire
⌀ One company remains in a station which usually has two companies
● Station is vacant by virtue of a previous dispatch

LEGEND :

R○ Station is occupied by a relocated unit
◉ Station is vacant by virtue of a previous relocation
⟶ Dispatch
----➔ Relocation
■ Location of a fire

Fig. MF-14


LADDERS
N
39
51
53
32
52
46
37
50
38
41
33
27
27-2
47
36
56
144
44
31
54
19
49
48
34
130
55
42
45
35
25
17
17-2
29
30
40
14
26
26-2
154
117

LEGEND :

○ Fire station with all companies available

⊗ Company has just been dispatched to a fire

∅ One company remains in a station which usually has two companies

● Station is vacant by virtue of a previous dispatch

LEGEND :

R○ Station is occupied by a relocated unit

◉ Station is vacant by virtue of a previous relocation

→ Dispatch

⇢ Relocation

■ Location of a fire

Fig. MF-15

LECTURE IF

INITIAL DISPATCH FOR FIRE SERVICE AUDIENCES

Time: Approx. 40 minutes

Objective: To show the students (a) that the history of alarms at an alarm box can provide valuable information for determining the number of units to be dispatched to a box alarm, and (b) that sometimes the closest unit may not be the best to send.

Activity	References and Notes
1. INTRODUCTION	
• How many should be sent?	Lecture follows Chapter V of Chaiken, Ignall, and Walker, Deployment Methodology for Fire Departments
-- Different cities have different policies	
-- When alarm rate is high, city might want to reduce its normal response to conserve resources	
-- There is a way to do this rationally	See also Carter, Ignall, and Rider, An Algorithm for the Initial Dispatch of Fire Companies
• Which ones should be sent?	
-- Always send closest when alarm rate is low	General ref.: Swersey, Model for Reducing Fire Engine Response Times
-- If alarm rate is high, this policy is not necessarily the best	

Activity	References and Notes
2. HOW MANY?	Ref.: Ignall et al., Improving the Deployment of New York City Fire Companies

(a) Objectives

- Try to send what is needed
- Get all units needed to the scene as rapidly as possible
- Don't have units make too many unnecessary responses

(b) How alarm is received is important

- Telephone - receive information that helps dispatcher decide
- Box - little information to go on
  - therefore, will restrict discussion to how many to send to box alarms

(c) When is there a decision?

- May want to hold back resources (not send full response) if alarm rate in region of incoming alarm is high enough so that the chance of having two alarms in progress at one time is not negligible (say 25%)

Activity	References and Notes
(d) The tradoff: Use send 1 ladder versus send 2 ladders as example	Figure IF-1

- Send 1 and need 2:
  - -- second ladder delayed
  - -- increased loss at fire
- Send 2 and need 1:
  - -- second ladder unavailable for another alarm (only important if there is a good probability that there will be another alarm while it is responding)
  - -- makes unnecessary response

Activity	References and Notes
2. HOW MANY? (continued)	
(e) Approach: Considers up to four factors (i) The probability that the incoming alarm is serious -- the greater the probability, the more units dispatched	
-- there are usually predictable box-to-box variations in probability serious, e.g., boxes 2277 and 2209 in Bronx	Figure IF-2. These are extreme cases, but near each other on the same street
-- this is the most important factor to consider	
- using this factor, can modify running cards--add to manual dispatching system (e.g., NYC's adaptive response)	Ref.: O'Hagan and Blum, *Technology Aids Fire Service*
(ii) The expected alarm rate in the area surrounding the alarm -- the greater the alarm rate, the fewer units dispatched -- implies that dispatch policy to the same location might vary by time of day	
(iii) The number of units available in the area surrounding the alarm -- the more units available, the more units dispatched -- if you want to include this factor, probably need a computer to keep track of status	Figure IF-3. If the department usually sends three units, if available, that would be a bad idea in this example
(iv) The workload of the companies involved -- the higher their workload, the fewer units dispatched	
(f) Method: Use a "cost" function to blend all the factors, then (for example) -- send 2 if cost is less than cost to send 1 -- send 1 if cost is lower than for send 2	

Activity | References and Notes

2. HOW MANY? (continued)

(g) Data needed if use all 4 factors in making decision

(i) For each alarm box

- Ordered list of closest engine and ladder companies
- Estimate of the probability that an incoming alarm from the box signals a serious fire (estimation procedure takes into account alarm history of box and alarm history of neighboring boxes)

Ref.: Carter and Rolph, New York City Fire Alarm Prediction Models: I. Box-Reported Serious Fires

(ii) For each fire-fighting company

- Expected alarm rate in its first-due area
- Number of responses made during some historical period
- Its current status (implies need for an on-line computer)

(iii) Way to calculate travel time between any house-alarm box pair

Refer to Lecture RF

Activity	References and Notes
3. WHICH?	Ref.: Carter, Chaiken, and Ignall, Response Areas for Two Emergency Units
• Sending closest not always best. Not sending closest can -- balance workload among companies -- provide faster response to alarms	
• Overly simplified example:	
• City with 2 companies and a send 1 dispatch policy Region A - high alarm rate Region B - low alarm rate -- Fire 1: closest company policy would dispatch Company a -- Suppose Fire 2 while Company a is busy: Company b must respond -- If send b to Fire 1 (near boundary), then a is available to respond to Fire 2. Net reduction in total response time (also, better balance in workload)	Figure IF-4
• Note: this policy appropriate only when overall alarm rates are high	

Activity	References and Notes
4. SCENARIO	
• Illustration of the circumstances under which analysis will suggest different choices for initial dispatch. The actual locations of ladder companies and alarm rates in various parts of the Bronx were used in constructing this scenario.	Bronx--borough of New York City
• At the start of the scenario, ladder companies 48, 42, and 44 have been dispatched to serious fires	Figure IF-5[*]
• An incident is reported by box alarm at box 2267. Recommended dispatch is two ladders. Ladders 17 and 55 are dispatched	Figure IF-6
• Another incident is reported by box alarm at box 2224	
• Now, because of unavailabilities in the area and a low probability of a serious fire at box 2224, the recommended dispatch is one ladder	
• Ladder 17-2 is dispatched and subsequently returns to quarters after finding a false alarm at box 2224	Not shown on maps
• Now a box alarm occurs at box 2574. Although the closest ladder company is busy (as was the case at box 2224), the recommended dispatch is two ladders in this case. Box 2574 is more likely to have a serious fire than box 2224	Figure IF-7
• At this point, the unavailability of ladders are as bad as if there were a third-alarm fire somewhere between ladder 55 and ladder 19. Relocations should be made	See Lecture MF
• An incident is reported by box alarm at box 2276, which is near box 2267. If relocations have not been made, one ladder should be dispatched. If relocations have been made, two ladders should be dispatched	Figure IF-8

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[*] The maps were current in 1973.

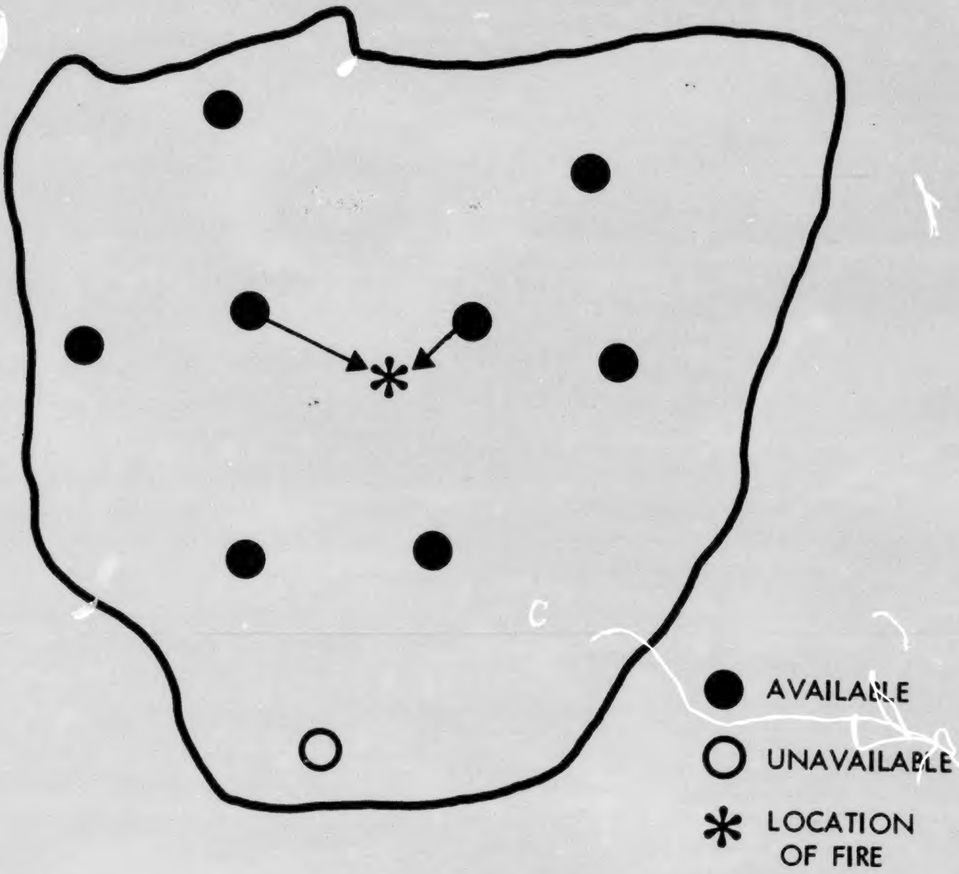

AVAILABLE
UNAVAILABLE
LOCATION OF FIRE

Fig. IF-1

Bronx box number	Predicted percent structural ('67 - '69 data)	Actual 1970 Data	
		Alarms	Structural fires
2277	0.4	96	0
2209	31.8	94	25

Fig. IF-2 — Structural fire predictions for two alarm boxes

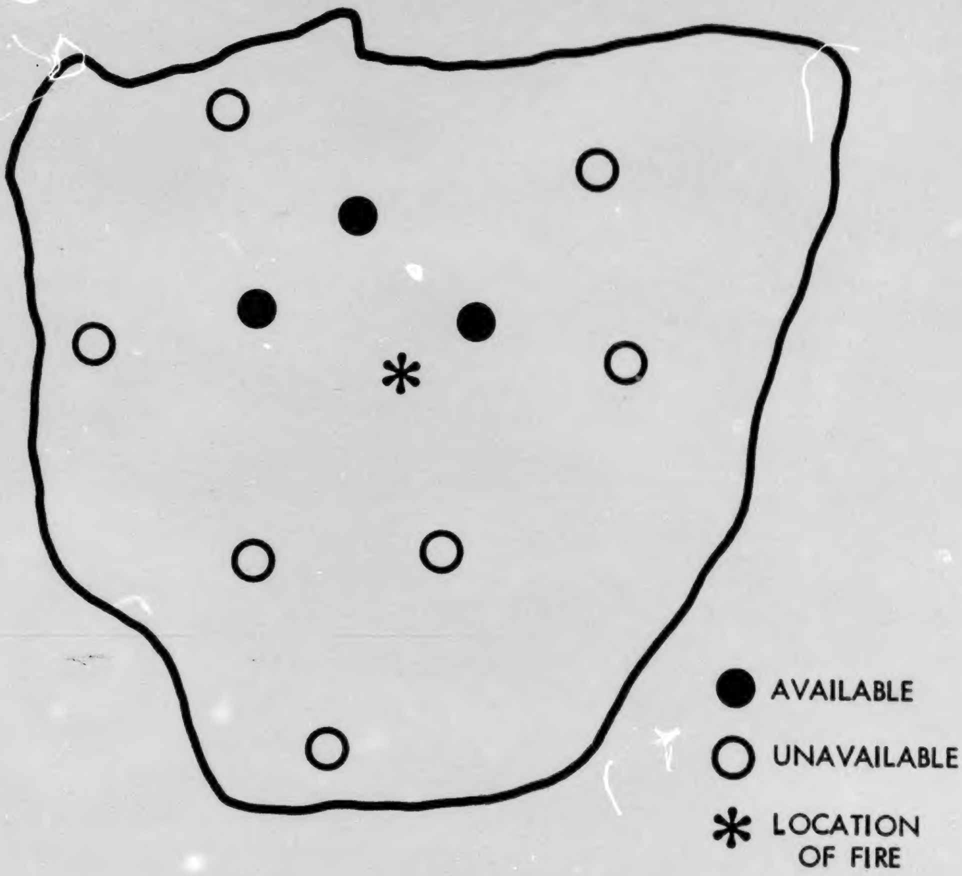

● AVAILABLE
○ UNAVAILABLE
* LOCATION OF FIRE

Fig. IF-3 — A problem with the traditional dispatching policy

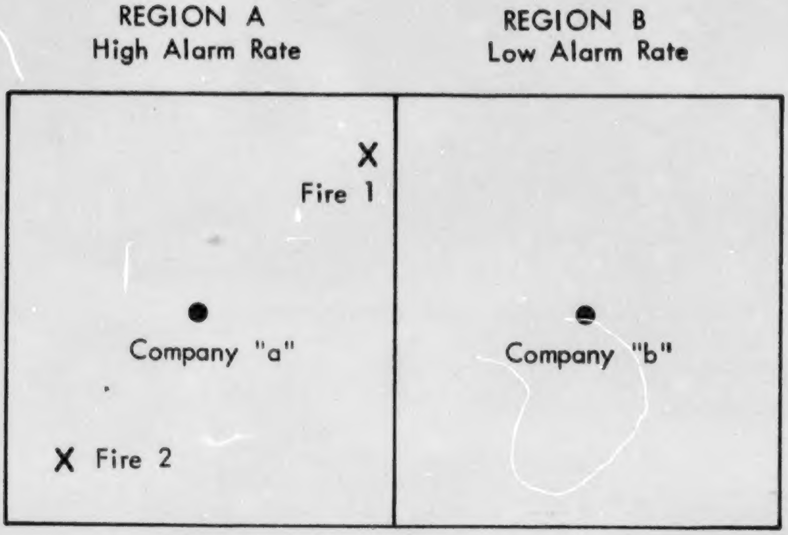
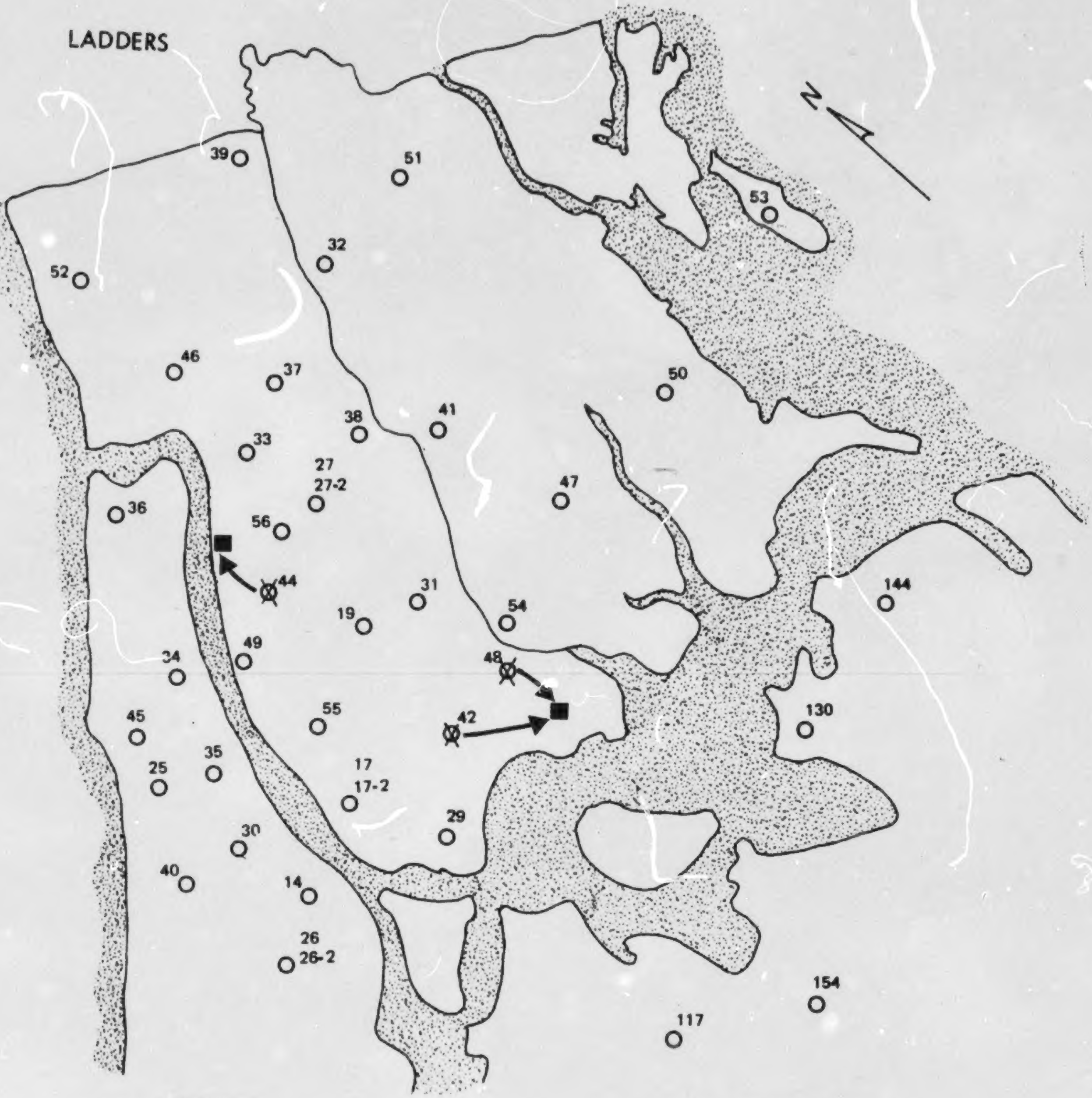

REGION A
High Alarm Rate
REGION B
Low Alarm Rate
X
Fire 1
Company "a"
X Fire 2
Company "b"

Fig. IF-4


LADDERS
N
39
51
53
52
32
46
37
50
38
41
33
27
27-2
47
36
56
44
31
144
19
54
34
49
48
130
42
45
55
25
35
17
17-2
29
30
40
14
26
26-2
154
117

LEGEND :

○ Fire station with all companies available
⊗ Company has just been dispatched to a fire
∅ One company remains in a station which usually has two companies
● Station is vacant by virtue of a previous dispatch

LEGEND :

R○ Station is occupied by a relocated unit
◉ Station is vacant by virtue of a previous relocation
——▶ Dispatch
- - - -▶ Relocation
■ Location of a fire

Fig. IF-5 — Status of Bronx ladder companies at the start of the scenario

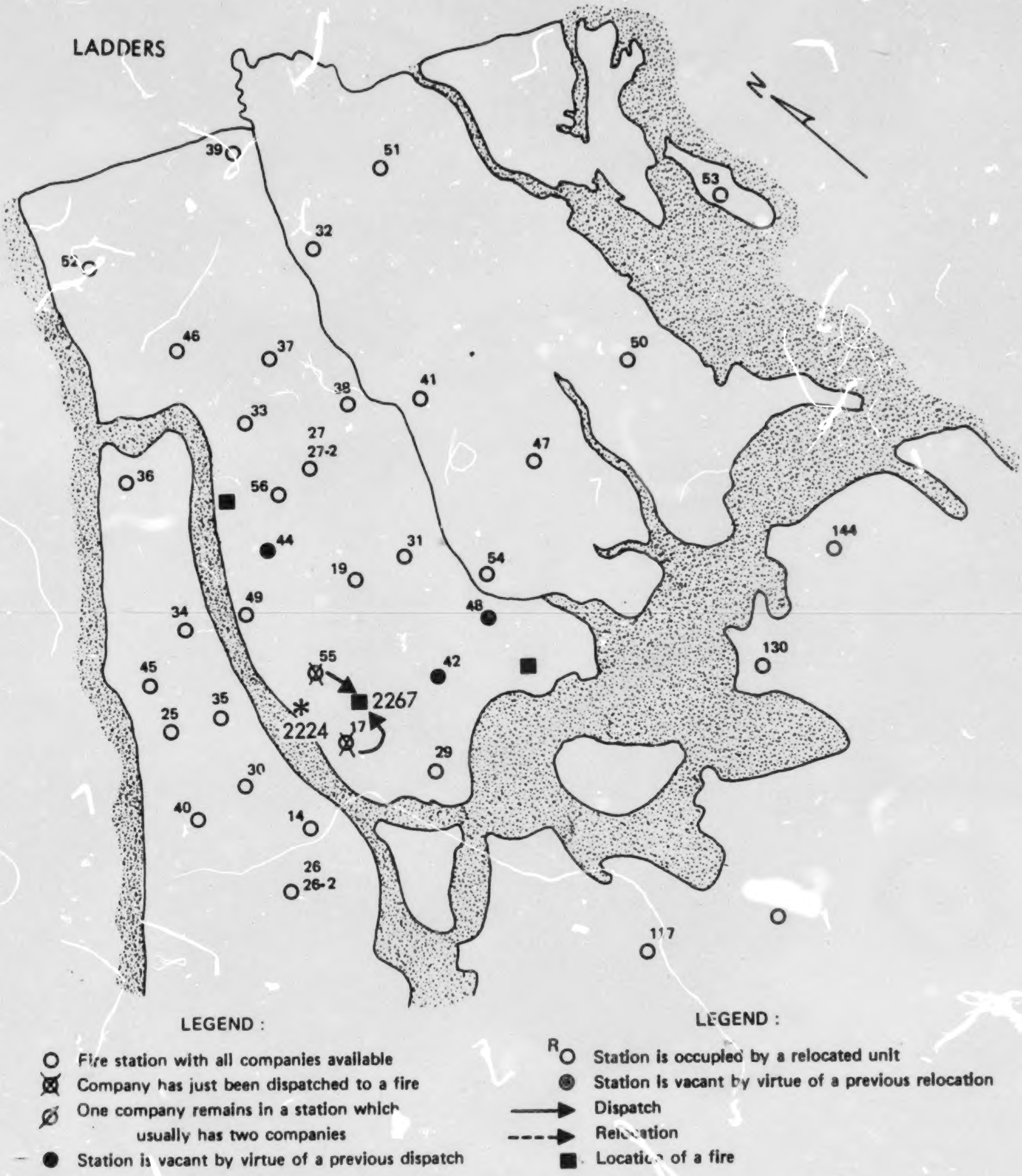

LADDERS
N
39
51
53
32
52
46
37
50
38
41
33
27
27-2
47
36
56
144
44
31
19
54
49
34
48
130
55
45
42
2267
35
25
2224
17
29
30
40
14
26
26-2
117
LEGEND :
○ Fire station with all companies available
☒ Company has just been dispatched to a fire
Ø One company remains in a station which usually has two companies
● Station is vacant by virtue of a previous dispatch
LEGEND :
R○ Station is occupied by a relocated unit
● Station is vacant by virtue of a previous relocation
→ Dispatch
--→ Relocation
■ Location of a fire

Fig. IF-6 — Status of Bronx ladder companies after Box 2267 is dispatched

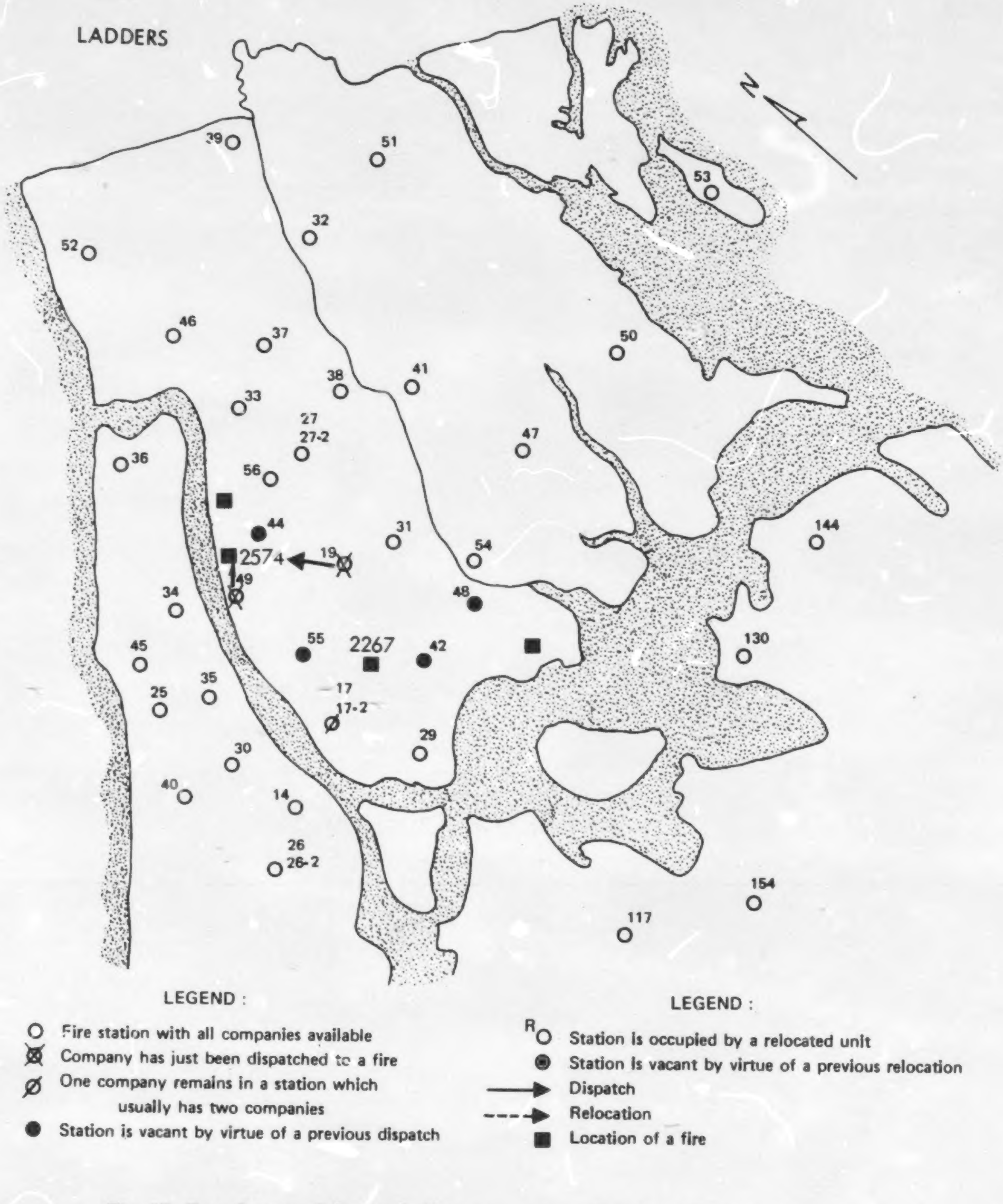
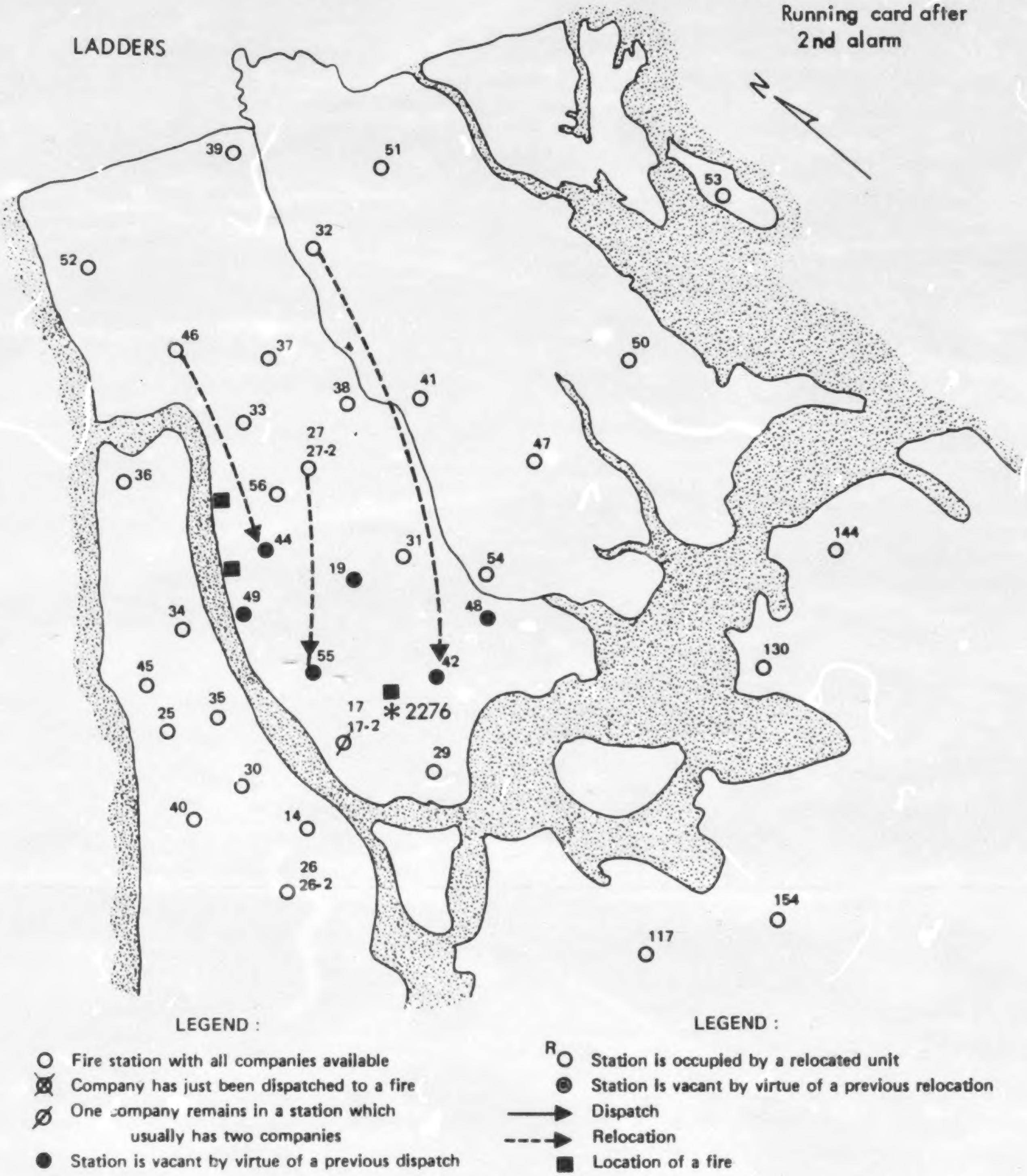

LADDERS
N
39
51
53
32
52
46
37
50
38
41
33
27
27-2
47
36
56
44
31
144
2574
19
54
149
48
34
55
2267
42
130
45
35
25
17
17-2
29
30
40
14
26
26-2
154
117
LEGEND :
○ Fire station with all companies available
☒ Company has just been dispatched to a fire
∅ One company remains in a station which usually has two companies
● Station is vacant by virtue of a previous dispatch
LEGEND :
ᴿ○ Station is occupied by a relocated unit
◉ Station is vacant by virtue of a previous relocation
→ Dispatch
⇢ Relocation
■ Location of a fire

Fig. IF-7 — Status of Bronx ladder companies after Box 2574 is dispatched


LADDERS
Running card after
2nd alarm
N
39
51
53
32
52
46
37
50
38
41
33
27
27-2
47
36
56
44
31
54
144
19
49
48
34
55
42
130
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17
17-2
*2276
35
25
29
30
40
14
26
26-2
154
117
LEGEND :
○ Fire station with all companies available
☒ Company has just been dispatched to a fire
Ø One company remains in a station which usually has two companies
● Station is vacant by virtue of a previous dispatch
LEGEND :
R○ Station is occupied by a relocated unit
◉ Station is vacant by virtue of a previous relocation
→ Dispatch
--→ Relocation
■ Location of a fire

Fig. IF-8 — Status of Bronx ladder companies at time of relocation

LECTURE AP

ALLOCATION OF POLICE PATROL

Time: Approx. 40 minutes

Objective: To provide an approach to answering the question of how many patrol cars to assign to each command by hour or tour.

Activity	References and Notes
1. INTRODUCTION	
• Topic is how many patrol cars to assign to each command by hour or tour -- "Command" is a general term for an administratively separate geographical area of the city. Variously called precinct, division, district, unit, or area -- A single patrol beat or sector is not a "command." A command can be characterized by the fact that if all its patrol cars were busy, a low-priority call for service would be queued	Follows Chaiken, *Patrol Allocation Methodology for Police Departments*, Chapter III For several hypothetical examples of policy issues related to allocation, see Chaiken and Dormont, *Patrol Car Allocation Model: User's Manual*
2. PRIORITY STRUCTURE	
• Find out what types of calls are actually handled by dispatchers as high priority (every effort will be made to locate a car to send immediately, even a supervisor or out-of-command car), medium priority (if in queue, will be dispatched as fast as possible), and low priority (can wait for dispatch)	Low-priority calls sometimes referred to as "nonemergencies"
• It doesn't help to think about which calls *should* fall in each priority level, unless the intention is to change the practices of dispatchers	

Activity	References and Notes
3. ESTIMATING CALL-FOR-SERVICE WORKLOAD	
• Need to know how many car-hours will be required to serve calls for service in each priority class in each hour of the day ("workload")	
• This can be done by estimating the number of calls in each class and the service times separately, and multiplying these together. Or estimate workload directly from workload data	"Service time" is how long the car is out of service handling the call
• Possible estimation methods -- commercially available computer programs (e.g., LEMRAS) -- average over past few weeks, adjust for seasonal trends -- graph and extrapolate	
• Estimates don't have to be super-accurate to be useful. Don't get wound up in trying to improve accuracy of predictions	
• Collect data from dispatcher's position	
• Commands found to have unusually long service times may have a management problem. Don't just allocate more cars to them	

Activity	References and Notes
4. ESTIMATE "EXTRA" UNAVAILABILITIES	
• f = average fraction of a car's tour that the car is unavailable for dispatch for reasons other than dispatch to a previous call	
-- includes meals, maintenance, patrol-initiated activities, arrest processing, etc.	Refer to Lecture RP
-- include time in court if this is only part of a tour	
• f may vary by command. In a given command, f may vary with call-for-service workload	
• Collect data at dispatcher's position	
• Draw graphs, calculate averages	
5. SET LIMIT ON QUEUING	
• Fraction of all calls queued	
• Average waiting time in queue for	
-- middle priority -- low priority	If these are reasonably small, high-priority calls will be handled fast
• Overall average waiting time	

Activity	References and Notes
6. NUMBER OF CARS NEEDED TO PREVENT QUEUING FROM EXCEEDING LIMIT	
• Consider a particular command and a particular hour of the day	
• N = number of cars to be fielded (we will try different values of N until we find the right one)	
• $(1-f)N$ = effective number of cars fielded	
• $(1-f)N$ must at least equal the estimated call-for-service workload in car-hours	To do the steady-state calculation, there must actually be an integer between (workload) and $(1-f)N$
• Start with N = next integer bigger than (workload)/$(1-f)$	
• See if queuing is below specified limits with $(1-f)N$ cars	
-- need graphs, tables, formulas, or a computer program	
• If not, increase N by one car and try again	
• Keep going. The first N that works tells how many cars are needed for queuing purposes	There are some details like averaging over a tour, but this is the general idea
7. EXAMPLE	
How many cars are needed to assure that less than 10% of calls are delayed in a command having 3.9 car-hours of work per hour and 30% of each car's time spent unavailable for reasons other than calls for service?	Figure AP-1. Answer is: 11 units

Activity	References and Notes
8. CRITERIA OTHER THAN QUEUING	
• See if the value of N chosen above is big enough so that (1-f)N effective cars give reasonable values for	
-- average travel time -- average patrol frequency -- patrol per outside crime -- (whatever you care about)	See Lecture RP for formulas. Average number of units available is (1-f)N - (workload)
• If not, increase N until these other criteria are met	
9. COMPARE WITH THE SIZE OF THE PATROL FORCE	
• Add the values of N (found above) across commands, or across hours of the day, or both	
• Do you have enough men to field that many car-hours?	
-- If no, some constraints must be relaxed, or some categories of calls must be screened out (no unit will respond), or the "extra" unavailabilities must be reduced by administrative change	
-- If yes, the extra cars can be allocated to commands or tours so as to minimize citywide average queuing delay. Or the extra cars can be assigned to special activities	This is just an example. You might want to minimize average probability of a delay or average response time (queuing + travel)

Activity	References and Notes
10. COMPUTER PROGRAM	Ref.: Chaiken and Dormont, Patrol Car Allocation Model
• Computer program is available to perform these calculations	
• Descriptive mode. User decides how many patrol cars are to be on duty in each command during each tour. Program displays	
-- Percent of time cars are busy on call-for-service work	
-- Preventive patrol frequency	
-- Average travel time	
-- Percent of calls queued	
-- Average waiting time in queue, by priority level	Program permits three priority levels
-- Average total response time	Queuing + travel
• Prescriptive mode	
(a) User sets limit on any of the measures listed above. Program calculates minimum number of cars needed	
(b) User specifies total car-hours that can be fielded. Program allocates them to tours or commands or both so as to minimize	
-- average percentage of calls placed in queue	
-- or, average waiting time for some priority level	
-- or, average response time	

Activity	References and Notes
11. DATA NEEDED FOR PROGRAM	
• Hours of the day at which tours begin. One tour can be an overlay	
• Call rates and service times by hour	Call rates broken down by priority
• Response and patrol speeds of cars	
• Number of outside crimes	To calculate number of crimes that will be intercepted by cars on patrol
• Unavailability parameters	These are used to calculate f (see item 4)
12. TYPES OF POLICY ISSUES THAT CAN BE ADDRESSED	For detailed hypothetical examples, see Chaiken and Dormont, Patrol Car Allocation Model: User's Manual
• Number of patrol officers needed to meet standards of performance	
• Which calls to "screen out" to improve performance levels with fixed resources	
• Allocation by time of day within each command	
• Possible benefits of an overlay tour	
• Where to assign new recruits	
• Deployment of a mobile patrol team (moves to different parts of the city from week to week)	
13. ADVANTAGES	
• Easy to use, once data are collected	
• Inexpensive to run on the computer	
14. DRAWBACKS	
• Calculations are approximate	
• User must estimate call rates and service times for the future	
• No information about variations within a command	See Lecture BP

f = .30

1-f = .7

Workload = 3.9

Workload/(1-f) = 5.57

Next integer	Effective number of cars	Percent of calls delayed*
6	4.2	86
7	4.9	56
8	5.6	36
9	6.3	22
10	7.0	12.1
11	7.7	7.3
Stop.		

*From tables, graphs, or computer program.

Fig. AP-1 — Example of allocation calculation

LECTURE BP

BEAT DESIGN
FOR POLICE SERVICE AUDIENCES

This is an optional added topic for Lecture AP

Time: Approx. 15 minutes

Objective: To describe an approach to designing police patrol beats or sectors

Activity	References and Notes
1. INTRODUCTION	General refs.: Larson, *Hypercube Queuing Model: User's Manual*; Chaiken, *Hypercube Queuing Model: Executive Summary*
• Topic is how to design patrol beats or patrol sectors: the areas covered by a single patrol car	
• The number of patrol beats in a command is determined from the allocation analysis	That is, use Patrol Car Allocation Model *before* designing beats
• Therefore, beats may change by time of day	
2. RULES OF THUMB	
• Shape of sector doesn't matter much, as long as it's compact	
• If travel speeds differ in two directions, the long dimension of the sector should be in the direction of the higher speeds	
• If beats don't overlap, the fraction of dispatches that are interdistrict (across beat boundaries) is at least as high as the fraction of time the average unit is unavailable	Ref.: Larson, *Measuring the Response Patterns of New York City Police Patrol Cars*
• Unit's workload is not equal to the workload generated in its beat	Because of interdistrict dispatches
• Burden of central location	Figure BP-1
-- Shaded parts of the command have many calls for service	
-- Number of calls for service is not high in the center	
-- Car in the center is very busy because it is the dispatcher's *second* choice for all the busy beats	

Activity	References and Notes
3. HYPERCUBE MODEL	
• Permits calculation of performance characteristics for trial beat designs. You have to work out the trial designs; program doesn't help	Later versions of program are being designed to recommend "optimal" beat designs
• Required data -- Divide city into small areas (smaller than a beat) -- Call-for-service data for the small areas -- Some way to estimate travel times between small areas .. coordinates of centers .. experimental trips .. estimates of local officers .. computerized road network	
• Performance measures calculated for each beat design -- Regionwide average travel time -- Regionwide workload imbalance -- Fraction of dispatches that are interdistrict -- Workload of each patrol car -- Average travel time to particular locations -- Average travel time in each beat -- Average travel time of each patrol car -- Fraction of responses in each beat handled by the beat's assigned car -- Fraction of each car's responses that take it out of its beat	
4. EXAMPLE OF APPLICATION	From Larson, "Illustrative Police Sector Redesign in District 4 in Boston"
• First map and table show original design of beats (called sectors) • Second set shows final design	Figures BP-2 to BP-5

Activity	References and Notes

5. ADVANTAGES

- Easy to use, after data have been collected
- Can handle overlapping beats, sergeant's cars, fairly complicated dispatching policies
- Inexpensive to run on a computer

6. DISADVANTAGES

- Assumes one car dispatched to each incident
- Not well suited to handle priorities

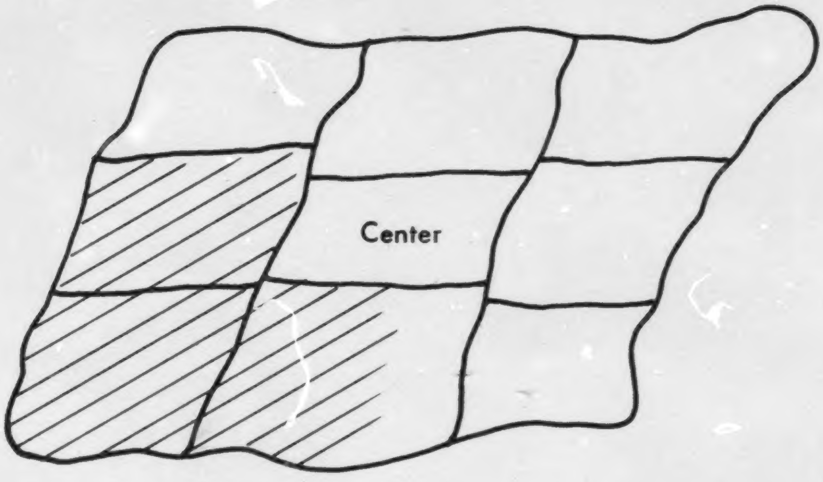

Fig. BP-1

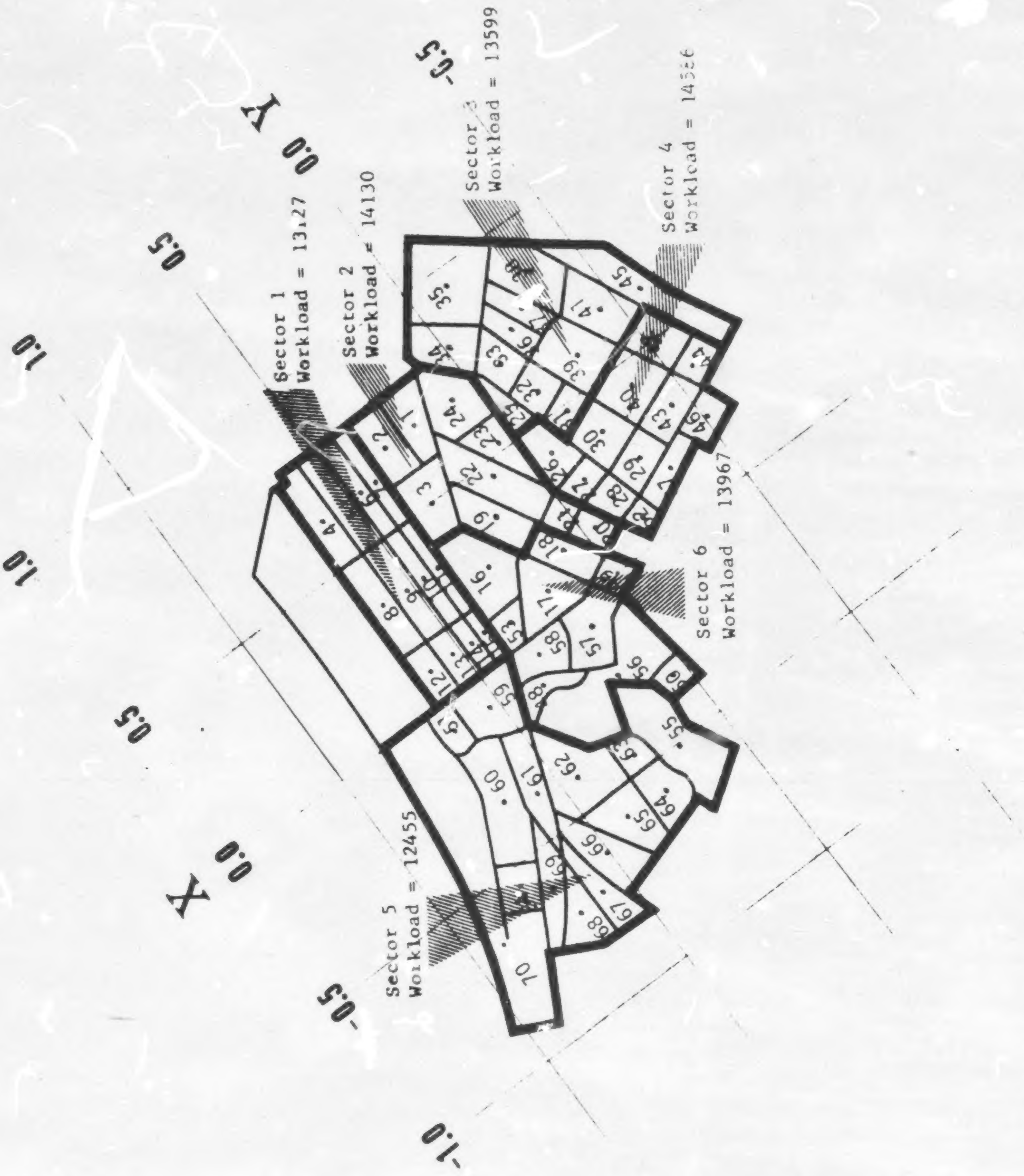
Y
X
-0.5
0.0
0.5
1.0
Sector 1
Workload = 13127
Sector 2
Workload = 14130
Sector 3
Workload = 13599
Sector 4
Workload = 14536
Sector 5
Workload = 12455
Sector 6
Workload = 13967

Fig. BP-2

Maximum workload imbalance = 26%

Region-wide average travel time = 3.402 minutes

Average travel time for queued calls = 5.178 minutes

Fraction of dispatches that are cross-sector = 0.485

Profile of Patrol Unit Operations

Patrol Unit No.	Workload	% of Mean	Fraction of Dispatches Out of Sector	% of Mean	Average Travel Time
1	0.519	103.8	0.539	111.3	3.432
2	0.559	111.7	0.576	118.7	3.378
3	0.496	99.2	0.477	98.5	3.090
4	0.490	98.0	0.426	87.9	3.180
5	0.428	85.7	0.373	77.0	3.978
6	0.507	101.5	0.487	100.4	3.414

Profile of Sector Operations

Sector Number	Fraction of District's Total Workload	% of Mean	Fraction of Dispatches that are Cross-Sector	Average Travel Time
1	0.160	96.2	0.503	3.312
2	0.172	103.6	0.542	3.120
3	0.166	99.7	0.480	3.324
4	0.178	106.9	0.474	3.258
5	0.152	91.3	0.412	4.218
6	0.170	102.4	0.491	3.258

Fig. BP-3

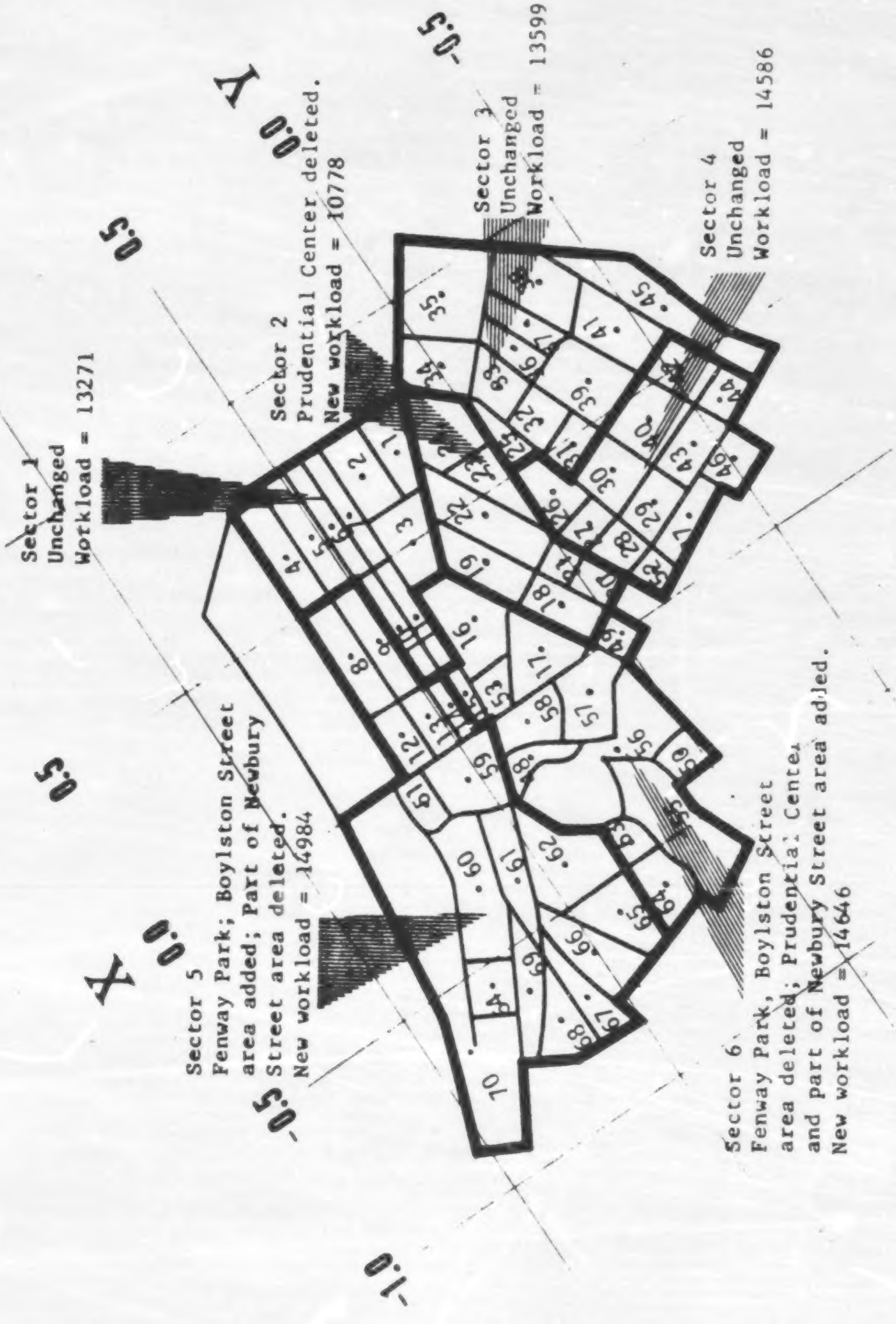
Sector 1
Unchanged
Workload = 13271
Sector 2
Prudential Center deleted.
New workload = 10778
Sector 3
Unchanged
Workload = 13599
Sector 4
Unchanged
Workload = 14586
Sector 5
Fenway Park; Boylston Street area added; Part of Newbury Street area deleted.
New workload = 14984
Sector 6
Fenway Park, Boylston Street area deleted; Prudential Center and part of Newbury Street area added.
New workload = 14646
X
Y
1.0
0.5
0.0
-0.5
-1.0

Fig. BP-4

Maximum workload imbalance = 5.48%

Regionwide average travel time = 3.426 minutes

Average travel time for queued calls = 5.178 minutes

Fraction of dispatches that are cross-sector = 0.483

Profile of Patrol Unit Operations

Patrol Unit No.	Workload	% of Mean	Fraction of Dispatches Out of Sector	% of Mean	Average Travel Time
1	0.499	99.7	0.495	102.5	3.222
2	0.512	102.4	0.611	126.6	3.318
3	0.497	99.4	0.479	99.3	3.192
4	0.502	100.4	0.453	93.7	3.174
5	0.485	97.0	0.398	82.3	4.074
6	0.505	100.1	0.456	94.5	3.612

Profile of Sector Operations

Sector Number	Fraction of District's Total Workload	% of Mean	Fraction of Dispatches that are Cross-Sector	Average Travel Time
1	0.162	97.3	0.482	2.958
2	0.132	79.0	0.496	2.886
3	0.166	99.7	0.481	3.234
4	0.178	106.9	0.486	3.204
5	0.183	109.8	0.468	4.524
6	0.179	107.3	0.488	3.534

Fig. BP-5

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[*] Case studies.

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